Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles

Draft EIS

June 2015

Docket No. NHTSA-2014-0074

NHTSA

www.nhtsa.gov

DRAFT ENVIRONMENTAL IMPACT STATEMENT

PHASE 2 FUEL EFFICIENCY STANDARDS FOR MEDIUM- AND HEAVY-DUTY ENGINES AND VEHICLES

MODEL YEAR 2018–2027

JUNE 2015

LEAD AGENCY:

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

COOPERATING AGENCIES:

U.S. ENVIRONMENTAL PROTECTION AGENCY AND U.S. DEPARTMENT OF ENERGY

Contents

List of Tables v
List of Figures xi
List of Acronyms and Abbreviations xv
Glossary xix

Summary S-1

Chapter 1 Purpose and Need for the Proposed Action 1-1
1.1 Introduction 1-1
1.2 Purpose and Need 1-3
1.3 National Environmental Policy Act and Joint Rulemaking Process 1-4
1.3.1 Building Blocks of the National Program 1-4
1.3.2 Proposed Action 1-6
1.4 Cooperating Agencies 1-13
1.5 Public Review and Comment 1-14
1.5.1 Scoping Comments 1-15
1.6 Next Steps in the National Environmental Policy Act and Joint Rulemaking Process 1-25

Chapter 2 Proposed Action and Alternatives and Analysis Methodologies 2-1
2.1 Introduction 2-1
2.2 Proposed Standards and Alternatives 2-2
2.2.1 HD Engines for Vocational Vehicles and Tractors 2-4
2.2.2 Classes 7–8 Tractors 2-8
2.2.3 Trailers 2-13
2.2.4 Classes 2–8 Vocational Vehicles 2-15
2.2.5 Classes 2b–3 Pickups and Vans 2-21
2.3 Direct and Indirect and Cumulative Impacts Analysis Methodologies 2-23
2.3.1 Resource Areas Affected and Types of Emissions 2-24
2.3.2 Energy Market Forecast Assumptions 2-25
2.3.3 Modeling Software 2-26
2.3.4 Approach to Scientific Uncertainty and Incomplete Information 2-29
2.4 Comparison of Alternatives 2-29
2.4.1 Direct and Indirect Effects 2-30
2.4.2 Cumulative Impacts 2-34

Chapter 3 Energy 3-1
3.1 Energy Intensity 3-2
3.2 Affected Environment 3-3
3.2.1 U.S. Production and Consumption of Primary Fuels 3-3
3.2.2 U.S. Energy Consumption by Sector 3-6
3.3 HD Vehicle Fuel Efficiency and U.S. Energy Security 3-10
3.4 Environmental Consequences 3-13
3.4.1 Direct and Indirect Impacts 3-14
3.4.2 Cumulative Impacts 3-15
3.4.3 Overall Benefits of Joint National Program 3-16
Chapter 4 AIR QUALITY 4-1
4.1 Affected Environment 4-1
4.1.1 Relevant Pollutants and Standards 4-1
4.1.2 Methodology 4-17
4.2 Environmental Consequences 4-35
4.2.1 Direct and Indirect Impacts 4-35
4.2.2 Cumulative Impacts 4-61
Chapter 5 Greenhouse Gas Emissions and Climate Change 5-1
5.1 Introduction 5-2
5.1.1 Uncertainty within the IPCC Framework 5-2
5.1.2 Climate Change and Its Causes 5-4
5.1.3 Anthropogenic Sources of Greenhouse Gases 5-8
5.1.4 Evidence of Climate Change 5-9
5.1.5 Future Climatic Trends and Expected Impacts 5-11
5.1.6 Black Carbon and Other Aerosols 5-12
5.2 Affected Environment 5-17
5.3 Analysis Methods 5-24
5.3.1 Methods for Modeling Greenhouse Gas Emissions 5-26
5.3.2 Social Cost of Carbon 5-27
5.3.3 Methods for Estimating Climate Effects 5-30
5.3.4 Tipping Points and Abrupt Climate Change 5-39
5.4 Environmental Consequences 5-40
5.4.1 Direct and Indirect Impacts 5-40
5.4.2 Cumulative Impacts 5-62
5.5 Health, Societal, and Environmental Impacts of Climate Change 5-75
5.5.1 Introduction 5-75

5.5.2 Sectoral Impacts of Climate Change 5-76
5.5.3 Regional Impacts of Climate Change 5-138
5.6 Non-Climate Cumulative Impacts of Carbon Dioxide 5-180
5.6.1 Affected Environment 5-180
5.6.2 Environmental Consequences 5-181
Chapter 6 Life-Cycle Impact Assessment of Vehicle ENERGY, Materials, and Technologies 6-1
6.1 Introduction 6-1
6.1.1 Overview of Life-Cycle Assessment in the Vehicle Context 6-2
6.1.2 Approach to HD Vehicle Life-Cycle Assessment Literature Synthesis 6-4
6.1.3 Comparability of Life-Cycle Assessment Findings by HD Vehicle Type 6-4
6.2 Energy Source Life-Cycle Considerations 6-5
6.2.1 Diesel and Gasoline 6-6
6.2.2 Natural Gas 6-8
6.2.3 Biofuels 6-15
6.3 Materials and Technologies 6-17
6.3.1 Vehicle Mass Reduction by Manufacturing Technologies 6-17
6.3.2 Vehicle Mass Reduction by Material Substitution 6-18
6.3.3 Tires 6-21
6.3.4 Aerodynamics and Drag 6-23
6.3.5 Trailers 6-25
6.3.6 Hybrid Vehicles and Batteries 6-26
6.3.7 Tractor Auxiliary Power Units 6-28
6.4 Conclusions 6-30
6.4.1 Energy Source Conclusions 6-30
6.4.2 Materials and Technologies Conclusions 6-30
Chapter 7 Other Impacts 7-1
7.1 Hazardous Materials and Regulated Waste 7-1
7.1.1 Affected Environment 7-1
7.1.2 Environmental Consequences 7-3
7.2 Historic and Cultural Resources 7-6
7.2.1 Affected Environment 7-6
7.2.2 Environmental Consequences 7-6
7.3 Noise 7-6
7.3.1 Affected Environment 7-6
7.3.2 Environmental Consequences 7-7
7.4 Safety Impacts on Human Health 7-8

7.5 Environmental Justice 7-9
7.5.1 Affected Environment 7-10
7.5.2 Environmental Consequences 7-11
7.6 Unavoidable Adverse Impacts 7-12
7.7 Short-Term Uses and Long-Term Productivity 7-13
7.8 Irreversible and Irretrievable Commitments of Resources 7-13

Chapter 8 Mitigation 8-1
8.1 Overview of Impacts 8-1
8.2 Mitigation Measures 8-2
8.3 Conclusion 8-5

CHAPTER 9 List of preparers and Reviewers 9-1
9.1 U.S. Department of Transportation 9-1
9.2 Consultant Team 9-3

Chapter 10 Distribution List 10-1
10.1 Federal Agencies 10-1
10.2 State and Local Government Organizations 10-5
10.3 Elected Officials 10-6
10.4 Federally Recognized Native American Tribes 10-8
10.5 Stakeholders 10-23

Chapter 11 References 11-1

Chapter 12 Index 12-1

Appendix A Air Quality Nonattainment Area Results

Appendix B Sources Identified in Scoping Comments

Appendix C Life-Cycle Assessment Studies

Tables

Page

1.3.2-1. HD Vehicle Segments by Gross Vehicle Weight Rating (pounds) 1-8

1.3.2-2. Summary of Phase 1 and Proposed Phase 2 HD Vehicle Programs 1-10

2.2-1. HD Vehicle Weight Classification 2-3

2.2.1-1. HD Engine Regulatory Subcategories 2-4

2.2.1-2. Alternative 1 (No Action Alternative) HD Tractor Diesel Engine Standards (over SET Cycle) 2-5

2.2.1-3. Alternative 1 (No Action Alternative) HD Tractor Engine Standards (over HD FTP Cycle) 2-5

2.2.1-4. Alternative 2 HD Tractor Diesel Engine Standards (over SET Cycle) 2-5

2.2.1-5. Alternative 2 HD Vocational Vehicle Diesel Engine Standards (over HD FTP Cycle) 2-6

2.2.1-6. Alternative 3 (Preferred Alternative) HD Tractor Diesel Engine Standards (over SET Cycle) 2-6

2.2.1-7. Alternative 3 (Preferred Alternative) HD Vocational Diesel Engine Standards (over HD FTP Cycle) 2-7

2.2.1-8. Alternative 4 HD Tractor Diesel Engine Standards (over SET Cycle) 2-7

2.2.1-9. Alternative 4 HD Vocational Vehicle Diesel Engine Standards (over HD FTP Cycle) 2-7

2.2.1-10. Alternative 5 HD Tractor Diesel Engine Standards (over SET Cycle) 2-8

2.2.1-11. Alternative 5 HD Vocational Vehicle Diesel Engine Standards (over HD FTP Cycle) 2-8

2.2.2-1. Alternative 1 (No Action Alternative) Classes 7–8 Tractor Standards 2-9

2.2.2-2. Alternative 2 Classes 7–8 Tractor Standards 2-10

2.2.2-3. Alternative 3 (Preferred Alternative) Classes 7–8 Tractor Standards 2-11

2.2.2-4. Alternative 4 Classes 7–8 Tractor Standards 2-12

2.2.2-5. Alternative 5 Classes 7–8 Tractor Standards 2-13

2.2.3-2. Alternative 2 HD Box Trailer Standards 2-14

2.2.3-3. Alternative 3 (Preferred Alternative) HD Box Trailer Standards 2-14

2.2.3-4. Alternative 4 HD Box Trailer Standards 2-15

2.2.3-5. Alternative 5 HD Box Trailer Standards 2-15

2.2.4-1. Alternative 1 (No Action Alternative) Diesel (CI) Vocational Vehicle Standards 2-16

2.2.4-2. Alternative 1 (No Action Alternative) Gasoline (SI) Vocational Vehicle Standards 2-16

2.2.4-3. Alternative 2 Diesel (CI) Vocational Vehicle Standards 2-17

2.2.4-4. Alternative 2 Gasoline (SI) Vocational Vehicle Standards 2-17

2.2.4-5. Alternative 3 (Preferred Alternative) Diesel (CI) Vocational Vehicle Standards 2-18

2.2.4-6. Alternative 3 (Preferred Alternative) Gasoline (SI) Vocational Vehicle Standards 2-18

2.2.4-7. Alternative 4 Diesel (CI) Vocational Vehicle Standards 2-19

2.2.4-8. Alternative 4 Gasoline (SI) Vocational Vehicle Standards 2-20

2.2.4-9. Alternative 5 Diesel (CI) Vocational Vehicle Standards 2-20

2.2.4-10. Alternative 5 Gasoline (SI) Vocational Vehicle Standards 2-21

2.2.5-1. Summary of Action Alternatives Examined for Phase 2 HD Pickup and Van Standards 2-22

2.3.3-1. Inventory of EIS Modeling Software 2-27

2.4.1-1. Direct and Indirect Impacts 2-31

2.4.2-1. Cumulative Impacts 2-35

3.4.1-1. Direct and Indirect HD Vehicle Fuel Consumption and Fuel Savings by Alternative, 2019–2050 3-14

3.4.2-1. Cumulative HD Vehicle Fuel Consumption and Fuel Savings by Alternative, 2014–2050 3-15

4.1.1-1. National Ambient Air Quality Standards 4-3

4.1.2-1. Nonattainment Areas for Ozone and PM2.5 4-21

4.1.2-2. Human Health and Welfare Effects of PM2.5 4-28

4.1.2-3. Benefit-per-ton Values (in 2012 dollars) Derived for PM-related Mortality and Morbidity, Adjusted to Reflect DOT's Value of Statistical Life 4-31

4.1.2-4. Valuation Metrics for Mortality and Morbidity Endpoints (in 2012 dollars) 4-32

4.1.2-2. Incidence-per-ton Values for Health Outcomes 4-34

4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts 4-36

4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Direct and Indirect Impacts 4-40

4.2.1-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts 4-42

4.2.1-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts 4-44

4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts 4-45

4.2.1-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Direct and Indirect Impacts 4-49

4.2.1-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts 4-51

4.2.1-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts 4-53

4.2.1-9. Nationwide Changes in Health Outcomes (cases per year) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b] 4-54

4.2.1-10. Nationwide Monetized Health Benefits (U.S. million dollars per year, 2012$) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts 4-55

4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts 4-62

4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Cumulative Impacts 4-66

4.2.2-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b] 4-68

4.2.2-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Cumulative Impacts 4-70

4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts 4-71

4.2.2-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Cumulative Impacts 4-75

4.2.2-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts 4-76

4.2.2-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Cumulative Impacts 4-79

4.2.2-9. Nationwide Changes in Health Outcomes (cases per year) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Cumulative Impacts 4-80

4.2.2-10. Nationwide Monetized Health Benefits (U.S. million dollars per year, 2012$) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Cumulative Impacts 4-81

5.1.1-1. Standard Terms Used to Define the Likelihood of an Occurrence of a Climate-related Event 5-4

5.3.2-1. Social Cost of Carbon, 2010–2050 (2012 dollars per $MTCO_2e$) 5-29

5.4.1-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles, 2018–2100 by Alternative 5-41

5.4.1-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All HD Vehicles by Alternative 5-44

5.4.1-3. Comparison of GHG Emissions Impacts between the Phase 2 HD Fuel Efficiency Improvement Program and GHG Reduction Initiatives in the United States 5-47

5.4.1-4. Reduced Monetized Damages from CO_2 Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative (net present value in 2015 in millions of 2012 dollars) 5-48

5.4.1-5. Sensitivity Analysis of Reduced Monetized Damages from CH4 and N2O Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative 5-48

5.4.1-6. Comparison of MAGICC Modeling Results and Reported IPCC Results 5-49

5.4.1-7. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise (GCAM Reference) by Alternative 5-50

5.4.1-8. Regional Changes to Warming and Seasonal Temperatures Summarized from the IPCC Fifth Assessment Report 5-54

5.4.1-9. Rates of Global Mean Precipitation Increase over the 21st Century, per Emissions Scenario 5-57

5.4.1-10. Global Mean Precipitation (percent Increase) Based on GCAM Reference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative 5-57

5.4.1-11. Regional Changes to Precipitation Summarized from the IPCC Fifth Assessment Report 5-58

5.4.1-12. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-Level Rise for Varying Climate Sensitivities for Selected Alternatives 5-61

5.4.2-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from all HD Vehicles 2018 to 2100 by Alternative 5-63

5.4.2-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All HD Vehicles by Alternative 5-65

5.4.2-3. Reduced Monetized Damages from CO_2 Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative 5-66

5.4.2-4. Sensitivity Analysis of Reduced Monetized Damages from CH_4 and N_2O Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative 5-66

5.4.2-5. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise by Alternative 5-68

5.4.2-6. Global Mean Precipitation (percent Increase) Based on GCAM6.0 Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative 5-71

5.4.2-7. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-Level Rise for RCP 4.5[a] for Selected Alternatives 5-72

5.4.2-8. Cumulative Impacts on CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-Level Rise for GCAM 6.0[a] for Selected Alternatives[b] 5-73

5.4.2-9. Cumulative Impacts on CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-Level Rise for GCAM Reference for Selected Alternatives 5-74

5.5.3-1. Observed and Projected Trends in Environmental Variables for the Northeast 5-141

5.5.3-2. Observed and Projected Trends in Environmental Variables for the Southeast 5-147

5.5.3-3. Observed and Projected Trends in Environmental Variables for the Midwest 5-152

5.5.3-4. Observed and Projected Trends in Environmental Variables for the Great Plains 5-156

5.5.3-5. Observed and Projected Trends in Environmental Variables for the Southwest 5-160

5.5.3-6. Observed and Projected Trends in Environmental Variables for the Northwest 5-165

5.5.3-7. Observed and Projected Trends in Environmental Variables for Alaska 5-170

5.5.3-8. Observed and Projected Trends in Environmental Variables for the Islands 5-175

6.2.1-1. Estimated Diesel Fuel Lifecycle Greenhouse Gas Emissions (g/million Btu) 6-8

6.2.2-2. Full Life Cycle Analysis Scenarios for CNG/LNG HD Vehicles (g/million Btu) 6-9

6.3.4-1. Summary of Currently-Available Aerodynamic Technologies 6-24

Figures

Page

2.2.5-1. Alternative 3 (Preferred Alternative) Phase 2 HD Fuel Consumption and CO_2 Standards for Diesel HD Pickups and Vans 2-22

2.2.5-2. Alternative 3 (Preferred Alternative) Phase 2 HD Fuel Consumption and CO_2 Standards for Gasoline HD Pickups and Vans 2-23

3.1-1. U.S. Energy Intensity, 1950–2011 3-2

3.2.1-1. U.S. Energy Production and Consumption by Source in 2011 and 2040 3-3

3.2.1-2. U.S. Natural Gas Production, 1950–2040 3-5

3.2.1-3. U.S. Petroleum Production, 1950–2040 3-5

3.2.2-1. Forecast U.S. Energy Consumption by End-Use Sector and Source Fuel in 2040 3-6

3.2.2-2. U.S. Consumption of Motor Gasoline, 1950–2040 3-9

3.2.2-3. U.S. Motor Gasoline and Diesel Fuel Consumption, 2000–2040 3-9

3.3-1. U.S. Petroleum Net Imports, 1950–2040 3-10

3.3-2. Total and Petroleum Trade Deficits, 1995–2013 3-11

3.3-3. Nominal and Real Oil Prices (2013 $) 3-12

3.3-4. Net Import Shares of Petroleum Products 3-12

3.3-5. Estimated Cumulative Effect of a 10 Percent Oil Price Shock on GDP 3-13

3.4.3-1. Phase 2 HD Impact on U.S. Transportation Diesel Fuel Consumption, 2015–2040 3-16

3.4.3-2. Phase 2 HD Impact on Projected U.S. Net Petroleum Imports and Net Energy Imports in 2040 3-17

4.1.1-1. Vehicle Miles Traveled Compared to Vehicle Emissions[a,b] 4-14

4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Direct and Indirect Impacts 4-37

4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Direct and Indirect Impacts 4-39

4.2.1-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts 4-43

4.2.1-4. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Direct and Indirect Impacts 4-46

4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Direct and Indirect Impacts 4-48

4.2.1-6 (a)–(f). Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts 4-52

4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Cumulative Impacts 4-64

4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Cumulative Impacts 4-65

4.2.2-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Cumulative Impacts 4-69

4.2.2-4. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Cumulative Impacts 4-73

4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Cumulative Impacts 4-74

4.2.2-6 (a)–(f). Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Cumulative Impacts 4-78

5.1.1-1. Some of the Climate System Processes Included in Climate Models 5-3

5.1.1-2. The Basis for the Confidence Level Given as a Combination of Evidence and Agreement 5-4

5.1.2-1. The Basis for the Confidence Level Given as a Combination of Evidence and Agreement 5-5

5.1.2-2. Human Influence on the Greenhouse Effect 5-6

5.1.2-3. Main Drivers of Climate Change 5-8

5.1.3-1. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2013 5-9

5.1.4-1. Observed Surface Temperature Change from 1901 to 2012[a] 5-10

5.1.5-1. Historical and Projected Carbon Emissions 5-11

5.1.5-2. End-of-Century (~2090–2100) Estimates of Maximum and Minimum Global Mean Sea-Level Rise 5-12

5.3-1. Cascade of Uncertainty in Climate Change Simulations 5-25

5.4.1-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles, 2018 to 2100 by Alternative 5-42

5.4.1-2. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative 5-43

5.4.1-3. Number of HD Vehicles Equivalent to CO_2 Reductions in 2025, Compared to the No Action Alternative 5-46

5.4.1-4. Atmospheric CO_2 Concentrations by Alternative 5-51

5.4.1-5. Reduction in Atmospheric CO2 Concentrations Compared to the No Action Alternative 5-51

5.4.1-6. Global Mean Surface Temperature Increase by Alternative 5-52

5.4.1-7. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative 5-52

5.4.2-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles 2018 to 2100 by Alternative 5-63

5.4.2-2. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative 5-64

5.4.2-3. Atmospheric CO_2 Concentrations by Alternative 5-68

5.4.2-4. Reduction in Atmospheric CO_2 Concentrations Compared to the No Action Alternative 5-69

5.4.2-5. Global Mean Surface Temperature Increase by Alternative 5-69

5.4.2-6. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative 5-70

5.5.2-1. The Three Lowest Layers in Earth's Atmosphere and the Location of the Ozone Layer 5-128

5.5.2-2. Northern Hemisphere Extent Anomalies[a,b] 5-134

5.5.2-3. Potential Tipping Points[a,b] 5-137

5.5.3-1. Average Annual Temperature (°C) in Alaska 5-168

5.5.3-2. Average Annual Precipitation (millimeters) in Alaska 5-169

5.6.2-1. As Oceans Absorb CO_2 They Become More Acidic[a,b] 5-183

6.2-1. U.S. HD Vehicle Energy Consumption by Source and Vehicle Type in 2011 and 2040 6-5

6.2-2. Forecast 2040 Fuel Use in Buses and Classes 2b–6 Trucks 6-6

6.2.2-1. Main Sources of Methane Leakage during Upstream Life-cycle Stages: Natural Gas Production, Processing, Transmission and Storage, and Distribution 6-10

6.2.2-2. U.S. Natural Gas Production by Source, Annual Energy Outlook 2014 Reference Case 6-12

6.2.2-3. Methane (CH_4) Flows during Hydraulic Fracturing 6-13

6.3.6-1. HD Vehicle Life-Cycle Emissions Comparisons between Conventional Diesel and Electric Power for Delivery Trucks in Gross Vehicle Weight Class 5 (16,001–19,500 lbs.) 6-27

Acronyms and Abbreviations

µg/m3	micrograms of a pollutant per cubic meter of air
ABS	anti-lock braking system
ACEEE	American Council for an Energy-Efficient Economy
AEO	Annual Energy Outlook
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
ANL	Argonne National Laboratory
APU	Auxiliary Power Unit
ATA	American Trucking Association
BAC	Battery Air Conditioning
BEV	battery electric vehicle
bpd	barrels per day
Btu	British thermal units
CAA	Clean Air Act
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAFE	Corporate Average Fuel Economy Program
CARB	California Air Resources Board
CBD	Center for Biological Diversity
CBO	Congressional Budget Office
CEQ	Council on Environmental Quality
CFA	Consumer Federation of America
CH_4	methane
CMAQ	Congestion Mitigation and Air Quality Improvement
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CRI	crash rate index
dB	decibels
DGE	diesel gallon equivalent
DNA	deoxyribonucleic acid
DNL	day-night average sound level
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DPM	diesel particulate matter
E10	10 percent ethanol by volume
E/GDP	energy-GDP ratio

E10	10 percent ethanol
E15	15 percent ethanol and 85 percent gasoline
E85	blend of gasoline and ethanol containing 51 to 83 percent ethanol
EDF	Environmental Defense Fund
EEI	Edison Electric Institute
EERE	Office of Energy Efficiency and Renewable Energy
EISA	Energy Independence and Security Act of 2007
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act of 1975
eTRU	electric trailer refrigeration unit
EV	electric vehicle
FAA	Federal Aviation Administration
FFV	flexible fuel vehicle
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
FY	fiscal year
g	grams
g/kWh	grams per kilowatt-hour
GCWR	gross combined weight rating
GDP	gross domestic product
GEM	Greenhouse Gas Emission Model
GHG	greenhouse gas
GIS	geographic information system
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model
GVW	gross vehicle weight
GVWR	gross vehicle weight rating
HEI	Health Effects Institute
HEV	hybrid electric vehicle
HFC	hydrofluorocarbon
HHS	U.S. Department of Health and Human Services
IARC	International Agency for Research on Cancer
IRIS	Integrated Risk Information System
ISO	International Organization for Standardization
kg/T	kilograms per metric ton
LCA	Life-Cycle Assessment
LNG	liquefied natural gas

LPG	liquefied petroleum gas
LRR	low rolling resistance
MDPV	medium-duty passenger vehicle
MJ	megajoule
$MMTCO_2e$	million metric tons CO_2e
MOBILE	Mobile Source Emission Factor
MOVES	Motor Vehicle Emission Simulator
mph	miles per hour
MSAT	mobile source air toxic
MY	model year
NAAQS	National Ambient Air Quality Standards
NaNiCl	nickel chloride
NAS	National Academy of Sciences
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NETL	National Energy Technology Laboratory
NG	natural gas
NGL	natural gas liquid
NHTSA	National Highway Traffic Safety Administration
NiCd	nickel cadmium
NiMH	nickel metal hydride
NO_2	nitrogen dioxide
NOI	Notice of Intent
NOx	nitrogen oxides
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NTEA	Association for the Work Truck Industry
NVH	noise vibration and harshness
OOIDA	Owner-Operator Independent Drivers Association
PbA	lead-acid
PEM	proton exchange membrane
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PM2.5	particulate matter measuring 2.5 microns in diameter
PM10	particulate matter measuring 10 microns in diameter
POM	polycyclic organic matter
ppm	parts per million
RFS2	Renewable Fuel Standards
RIA	Regulatory Impact Analysis

SIP	State Implementation Plan
SO_2	sulfur dioxide
SOFCs	solid oxide fuel cell
SOx	oxides of sulfur
TRU	trailer refrigeration units
TS&D	transportation, storage, and distribution
U.S.C.	U.S. Code
UAW	International Union, United Automobile, Aerospace & Agricultural Implement Workers of America
VMT	vehicle miles traveled
VOC	volatile organic compound
VSL	value of statistical life
WBS	wide-base single
WTI	West Texas Intermediate

Glossary

The glossary provides the following definitions of technical and scientific terms, as well as plain English terms used differently in the context of this EIS.

Term	Definition
Adaptation	Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, including anticipatory and reactive, private and public, and autonomous and planned.
Acrolein	A colorless irritant liquid aldehyde with a piercing, acrid smell.
Aerodynamic diameter	The diameter of the spherical particle with a density of 1,000 kg/m^3 and the same settling velocity as the irregular particle.
Albedo	Surfaces on Earth reflect solar radiation back to space. The reflective characteristic, known as albedo, indicates the proportion of incoming solar radiation that the surface reflects. High albedo has a cooling effect because the surface reflects rather than absorbs most solar radiation.
Anthropogenic	Resulting from or produced by human beings.
Biofuel	Energy sources made from living things, or the waste that living things produce.
Biosphere	The part of the Earth system comprising all ecosystems and living organisms, in the atmosphere, on land (terrestrial biosphere) or in the oceans (marine biosphere), including dead organic matter, such as litter, soil organic matter, and oceanic detritus.
Black carbon	The most strongly light-absorbing component of particulate matter, and formed by the incomplete combustion of fossil fuels, biofuels, and biomass.
Carbon sink	Any process, activity, or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.
Compressed natural gas	Methane stored at high pressure.
Coral bleaching	The paling in color that results if coral loses its symbiotic, energy providing, organisms.
Criteria pollutants	Carbon monoxide (CO), airborne lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and fine particulate matter (PM).
Cryosphere	The portion of Earth's surface that is frozen water, such as snow, permafrost, floating ice, and glaciers.
Dry natural gas	Also known as *consumer-grade natural gas*, dry natural gas is gas that remains after lease, field, and/or plant separation and any volumes of non-hydrocarbon gases have been removed where they occur in sufficient quantity to render the gas unmarketable.

Term	Definition
Ecosystem	A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, all of Earth.
Endemic	Restricted to a region.
Eutrophication	Enrichment of a water body with plant nutrients.
Evapotranspiration	The combined process of water evaporation from Earth's surface and transpiration from vegetation.
Fluorinated gases	Fluorinated greenhouse gases (GHGs) or gases include perfluorinated compounds (PFCs), hydrofluorocarbons (HFCs), sulfur hexaflouride (SF_6), and nitrogen trifluoride (NF_3).
Fuel efficiency	How much fuel a vehicle requires to perform a certain amount of work (e.g., how many tons it can carry per mile traveled). A vehicle is more fuel-efficient if it can perform more work while consuming less fuel.
GREET model	Model developed by Argonne National Laboratory that provides estimates of the energy and carbon contents of fuels as well as energy use in various phases of fuel supply.
Hazardous air pollutants	Substances defined as hazardous by the 1990 CAA amendments, including certain volatile organic compounds (VOCs), compounds in particulate matter, pesticides, herbicides, and radionuclides that present tangible hazards, based on scientific studies of human (and other mammal) exposure.
Hydrocarbon	An organic compound consisting entirely of hydrogen and carbon.
Hydrology	The science dealing with the occurrence, circulation, distribution, and properties of Earth's water.
Hydrosphere	The component of the climate system comprising liquid surface and subterranean water, such as oceans, seas, rivers, freshwater lakes, and underground water.
Lifetime fuel consumption	Total volume of fuel used by a vehicle over its lifetime.
Liquefied natural gas (LNG)	A natural gas (predominantly methane) that has been converted to liquid form for ease of storage or transport.
Maximum lifetime of vehicles	The age after which less than 2% of the vehicles originally produced during a model year remains in service.
Meridional Overturning Circulation	A mechanism for heat transport in the North Atlantic Ocean, by which warm waters are carried north and cold waters are carried toward the equator.
Mobile source air toxics (MSATs)	Hazardous air pollutants emitted from vehicles that are known or suspected to cause cancer or other serious health and environmental effects. MSATs included in this analysis are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter, and formaldehyde.

Term	Definition
MOVES model	The Motor Vehicle Emissions Simulator (MOVES) model used to calculate tailpipe emissions.
NEPA scoping process	An early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action.
Nonattainment area	Regions where concentrations of criteria pollutants exceed federal standards. Nonattainment areas are required to develop and implement plans to comply with the National Ambient Air Quality Standards (NAAQS) within specified time periods.
Ocean acidification	A decrease in the pH of sea water due to the uptake of anthropogenic carbon dioxide (CO_2).
Ozone	A photochemical oxidant and the major component of smog.
Particulate matter (PM)	Substances that exist as discrete particles. PM includes dust, dirt, soot, smoke, and liquid droplets directly emitted into the air.
Pathways of fuel supply	Imports to the United States of refined gasoline and other transportation fuels, domestic refining of fuel using imported petroleum as a feedstock, and domestic fuel refining from crude petroleum produced within the United States.
Permafrost	Ground (soil or rock and included ice and organic material) that remains at or below zero degrees Celsius for at least two consecutive years.
Photochemical modeling	The mathematical simulation of the chemical and meteorological processes associated with the formation of ozone.
Polycyclic organic matter (POM)	A broad class of compounds that includes the polycyclic aromatic hydrocarbon compounds (PAHs). Formed primarily from combustion and present in the atmosphere in particulate form.
Primary fuel	Energy sources consumed in the initial production of energy.
Rebound effect	A situation in which improved fuel economy reduces the fuel cost of driving and leads to additional use of medium- and heavy-duty (HD) vehicles and thus increased emissions of criteria pollutants by HD vehicles.
Renewable energy	Energy coming from resources that are naturally replenished on the human timescale, e.g., sunlight, wind, rain, tides, waves, and geothermal heat.
Saltwater intrusion	Displacement of fresh surface water or groundwater by the advance of saltwater due to its greater density. This process usually occurs in coastal and estuarine areas due to reducing land-based influence (either from reduced runoff and associated groundwater recharge, or from excessive water withdrawals from aquifers) or increasing marine influence (relative sea-level rise).

Term	Definition
Sea-ice extent	Measurement of the area of ocean where there is at least some sea ice. Usually, scientists define a threshold of minimum concentration to mark the ice edge; the most common cutoff is at 15 percent.
Shale gas	Natural gas that is trapped within shale formations, which are fine-grained sedimentary rocks that can be rich resources of petroleum and natural gas.
Social cost of carbon (SCC)	An estimate of the economic damages associated with a small increase in CO_2 emissions.
Survival rate	The proportion of vehicles originally produced during a model year that are expected to remain in service at the age they will have reached during each subsequent year.
Thermal expansion (of water)	The tendency of water to change in volume in response to a change in temperature through heat transfer.
Tipping point	A phrase used to describe situations in which the climate system reaches a point at which a disproportionately large or singular response in a climate-affected system occurs as a result of only a moderate additional change in the inputs to that system.
Transportation, storage, and distribution (TS&D)	The linkage of energy supplies, energy carriers, or energy by-products to intermediate and end users.
Upstream emissions	Emissions associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels.
Vehicle miles traveled	Total number of miles driven.
Volatile organic compound	Emitted as gases from certain solids or liquids which are emitted by a wide variety of products.
Volpe model	Used to calculate tailpipe emissions for Classes 2b–3 vehicles.

SUMMARY

Foreword

The National Highway Traffic Safety Administration (NHTSA) prepared this environmental impact statement (EIS) to analyze and disclose the potential environmental impacts of the proposed fuel efficiency standards for commercial medium-duty and heavy-duty on-highway engines, vehicles, and trailers (hereinafter referred to collectively as "HD vehicles") for model years (MYs) 2018 and beyond (the Proposed Action).[1] NHTSA prepared this document pursuant to Council on Environmental Quality (CEQ) National Environmental Policy Act (NEPA) implementing regulations, U.S. Department of Transportation (DOT) Order 5610.1C, and NHTSA regulations.

This EIS compares the potential environmental impacts of five alternatives to regulating HD vehicle fuel efficiency for MYs 2018 and beyond, including Alternative 3 (the Preferred Alternative/Proposed Action), three other action alternatives, and Alternative 1 (the No Action Alternative), and analyzes the direct, indirect, and cumulative impacts of each action alternative relative to the No Action Alternative. The action alternatives NHTSA selected for evaluation encompass a reasonable range of alternatives to evaluate the potential environmental impacts of the Proposed Action and alternatives under NEPA. EIS chapters and appendices provide or reference all relevant supporting information.

Background

The Energy Policy and Conservation Act of 1975 (EPCA) mandated that NHTSA establish and implement a regulatory program for motor vehicle fuel economy. As codified in Chapter 329 of Title 49 of the U.S. Code (U.S.C.), and as amended by the Energy Independence and Security Act of 2007 (EISA), EPCA sets forth specific requirements concerning the establishment of average fuel economy standards for passenger cars and light trucks, which are motor vehicles with a gross vehicle weight rating (GVWR) of less than 8,500 pounds and medium-duty passenger vehicles with a GVWR of less than 10,000 pounds. This regulatory program, known as the Corporate Average Fuel Economy Program (CAFE), was established to reduce national energy consumption by increasing the fuel economy of these vehicles.

EISA provided DOT—and NHTSA, by delegation—new authority to implement, through rulemaking and regulations, "a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program designed to achieve the maximum feasible improvement" for motor vehicles with a GVWR of 8,500 pounds or greater, except for medium-duty passenger vehicles that are already covered under CAFE. This broad sector (HD vehicles, as described above)—ranging from large pickups to sleeper-cab tractors—represents the second-largest contributor to oil consumption and greenhouse gas (GHG) emissions from the transportation sector, after light-duty passenger cars and trucks. EISA directs NHTSA to "adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols that are appropriate, cost-effective, and technologically feasible for commercial medium- and heavy-duty on-highway vehicles and work trucks." This new authority permits NHTSA to set "separate standards for different classes of vehicles."

[1] The Proposed Action would establish new standards beginning with MY 2018 for trailers and MY 2021 for all of the other heavy-duty vehicle and engine categories, with stringency increases through MY 2027 for some segments. Standards would remain at the final stringency levels until amended by a future rulemaking.

Consistent with these requirements and in consultation with the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE), NHTSA established the first fuel efficiency standards for HD engines and vehicles in September 2011, as part of a comprehensive HD National Program to reduce GHG emissions and fuel consumption for HD vehicles (trailers were not included in that phase). Those fuel-efficiency standards constitute the first phase (Phase 1) of the NHTSA HD Fuel Efficiency Improvement Program. They were established to begin in MY 2016 and remain stable through MY 2018, consistent with EISA requirements. Although EISA prevented NHTSA from enacting mandatory standards before MY 2016, NHTSA established voluntary compliance standards for MYs 2014–2015 prior to mandatory regulation in MY 2016. Throughout this EIS, NHTSA refers to the rulemaking and EIS associated with the MY 2014–2018 HD vehicle fuel efficiency standards described in this paragraph as "Phase 1" or the "Phase 1 HD National Program."

In February 2014, the White House directed NHTSA and EPA to develop and issue the next phase of HD vehicle fuel efficiency and GHG standards by March 2016. Consistent with this directive, NHTSA is proposing fuel efficiency standards for HD engines, vehicles, and trailers as part of a joint rulemaking with EPA to establish what is referred to as the Phase 2 HD National Program (also referred to as "Phase 2"). As with Phase 1 and as directed by EISA, NHTSA's Phase 2 HD Fuel Efficiency Improvement Program rulemaking is being conducted in consultation with EPA and DOE.

Pursuant to NEPA, federal agencies that propose "major federal actions significantly affecting the quality of the human environment" must, "to the fullest extent possible," prepare "a detailed statement" on the environmental impacts of the proposed action, including alternatives to the proposed action. To inform its development of Phase 2, NHTSA prepared this EIS, which analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives, including a Preferred Alternative, pursuant to CEQ NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations.

Purpose and Need for the Proposed Action

NEPA requires proposed alternatives to be based on the action's purpose and need. The purpose of this rulemaking is to continue to promote EPCA's goals of energy independence and security, as well as to improve environmental outcomes and national security, by continuing to implement an HD Fuel Efficiency Improvement Program that is "designed to achieve the maximum feasible improvement." Congress specified that, as part of the HD Fuel Efficiency Improvement Program, NHTSA must adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols. These required aspects of the program must be appropriate, cost effective, and technologically feasible for HD vehicles. In developing Phase 2, NHTSA has continued to consider these EISA requirements as well as relevant environmental and safety considerations.

Although the standards established under the Phase 1 HD National Program have locked in long-lasting gains in fuel efficiency, HD vehicle fuel consumption is still projected to grow as more trucks are driven more miles. For this reason, new standards extending beyond Phase 1 are needed to improve energy security, save money for consumers and businesses, reduce harmful air pollution, and lower costs for transporting goods. The Proposed Action and alternatives analyzed in this EIS have, therefore, been developed to reflect the purpose and need specified by EISA, the Phase 1 HD National Program, and the 2014 White House direction on developing Phase 2 HD vehicle fuel efficiency and GHG standards.

Proposed Action and Alternatives and Analysis Methodologies

NEPA requires an agency to compare the potential environmental impacts of its proposed action and a reasonable range of alternatives. NHTSA's Proposed Action is to set HD vehicle fuel efficiency standards for MYs 2018 and beyond as part of joint rulemaking with EPA to establish what is referred to as the Phase 2 HD National Program, in accordance with EPCA, as amended by EISA. The specific alternatives NHTSA selected, described below and in Sections 2.2-2 and 2.2-3 of this EIS, encompass a reasonable range within which to set HD vehicle fuel efficiency standards and evaluate potential environmental impacts under NEPA. Pursuant to CEQ regulations, the agency has included a No Action Alternative (Alternative 1), which assumes that NHTSA would not issue a rule regarding HD vehicle fuel efficiency standards beyond Phase 1, and assumes that NHTSA's Phase 1 standards and EPA's Phase 1 HD vehicle GHG standards would continue indefinitely. This alternative provides an analytical baseline against which to compare the environmental impacts of the four action alternatives.

Alternatives

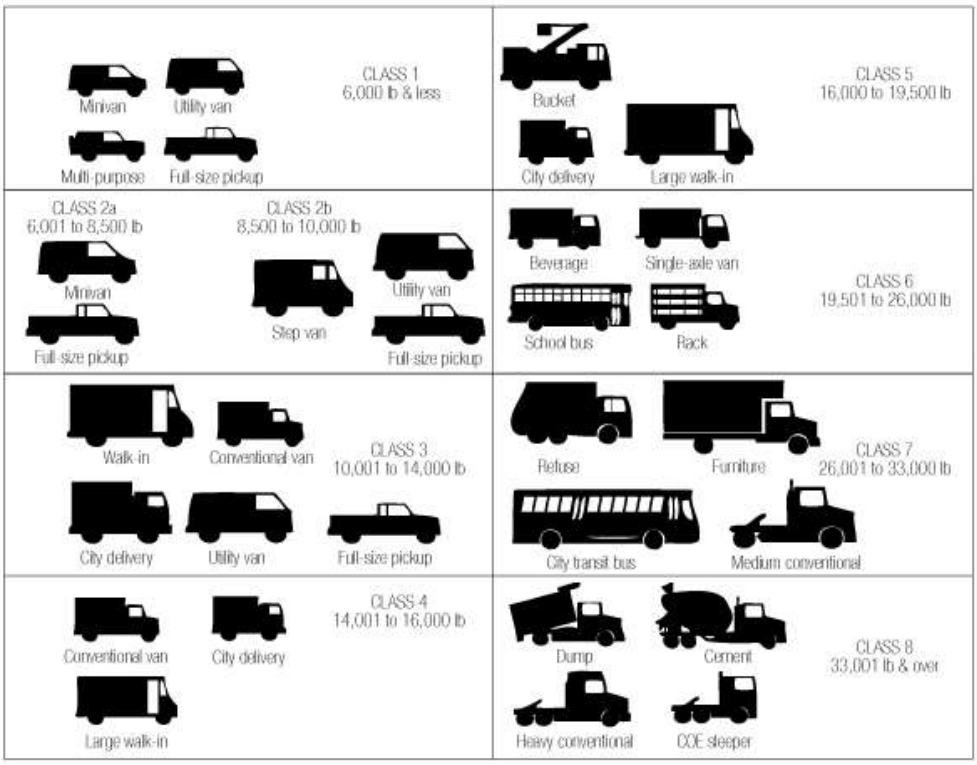
The specific alternatives selected by NHTSA encompass a reasonable range of alternatives by which to evaluate the potential environmental impacts of Phase 2 of the HD Fuel Efficiency Improvement Program under NEPA. At one end of this range is the No Action Alternative, which assumes that no action would occur under the HD National Program. In addition to the No Action Alternative, NHTSA examined four action alternatives, each of which would regulate the separate segments of the HD vehicle fleet differently. Each of these action alternatives would include fuel consumption standards for engines used in Classes 2b–8 vocational vehicles and tractors (specified as gallons of fuel per horsepower-hour [gal/100 bhp-hr]); overall vehicle standards for HD pickups and vans (specified as gal/100 miles), Classes 2b–8 vocational vehicles, and Classes 7–8 tractors (specified as gallons of fuel per 1,000 ton payload miles [gal/1,000 ton-miles]); and standards for certain trailers pulled by Classes 7–8 tractors (specified as gal/1,000 ton-miles associated with "standard" reference tractors). The Preferred Alternative and Alternative 4 were designed to achieve similar fuel efficiency and GHG emissions levels in the long term, but with Alternative 4 being accelerated in its implementation timeline. Specifically, the MY 2027 standards under the Preferred Alternative be achieved under Alternative 4 in MY 2025 for HD pickups and vans and in MY 2024 for vocational vehicles, tractors, and engines. Under Alternative 2, standards are less stringent than the Preferred Alternative. Alternative 5 represents more stringent standards compared to Alternatives 3 and 4, with the same implementation timeline as Alternative 4. Alternatives 2 through 5 would regulate the same vehicle categories, but at increasing levels of stringency, with Alternative 2 being the least stringent alternative and Alternative 5 being the most stringent.

Table S-1 and Figure S-1 show the vehicle classifications that are the subject of the proposed rule. For more details about these vehicle categories and the specific standards for the Preferred Alternative and other action alternatives, *see* Section 2.2, the Notice of Proposed Rulemaking (NPRM), and the Preliminary Regulatory Impact Analysis (PRIA).

Table S-1. HD Vehicle Categories by Gross Vehicle Class Weight Rating (pounds)

Class 2b	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
8,501–10,000	10,001–14,000	14,001–16,000	16,001–19,500	19,501–26,000	26,001–33,000	>33,000
HD Pickups and Vans (work trucks)						
Vocational Vehicles (*e.g.*, van trucks, utility "bucket" trucks, tank trucks, refuse trucks, buses, fire trucks, flat-bed trucks, and dump trucks)						
					Tractors (for combination tractor-trailers)	

Figure S-1. HD Vehicle Categories



Potential Environmental Consequences

This section describes how the Proposed Action and alternatives could affect energy use, air quality, and climate (including non-climate impacts of carbon dioxide [CO_2]), as reported in Chapters 3, 4, and 5 of the EIS, respectively. The EIS also provides a life-cycle impact assessment of vehicle energy, materials, and technologies, as reported in Chapter 6 of the EIS. This EIS also qualitatively describes potential additional impacts on water resources, biological resources, hazardous materials and regulated wastes, noise, and environmental justice, as reported in Chapter 7 of the EIS.

The impacts on energy use, air quality, and climate described in the EIS include *direct*, *indirect*, and *cumulative impacts*. Direct impacts occur at the same time and place as the action. Indirect impacts occur later in time and/or are farther removed in distance. Cumulative impacts are the incremental direct and indirect impacts resulting from the action added to those of other past, present, and reasonably foreseeable future actions.

To derive the impacts of the action alternatives, NHTSA compares the action alternatives to the No Action Alternative. The action alternatives in the direct and indirect impacts analysis and the cumulative impacts analysis are the same, but the No Action Alternative under each analysis reflects different assumptions to distinguish between direct and indirect impacts versus cumulative impacts.

- The analysis of direct and indirect impacts compares action alternatives with a No Action Alternative that generally reflects a small forecast improvement in the average fuel efficiency of new HD vehicles after 2018 due to market-based incentives for improving fuel efficiency. In this way, the analysis of direct and indirect impacts isolates the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the proposed rule, and not attributable to reasonably foreseeable future actions by manufacturers after 2018 to improve new HD vehicle fuel efficiency even in the absence of new regulatory requirements.
- The analysis of cumulative impacts compares action alternatives with a No Action Alternative that generally reflects no forecast improvement in the average fuel efficiency of new HD vehicles after 2018. As a result, the difference between the environmental impacts of the action alternatives and the cumulative impacts baseline reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 (i.e., reasonably foreseeable future changes in HD vehicle fuel efficiency) and the direct and indirect impacts of the Phase 2 standards associated with each action alternative. Therefore, this analysis reflects the cumulative impacts of reasonably foreseeable improvements in fuel efficiency after 2018 due to market-based incentives in addition to the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

Energy

NHTSA's proposed Phase 2 standards would regulate HD vehicle fuel efficiency and, therefore, affect U.S. transportation fuel consumption. Transportation fuel comprises a large portion of total U.S. energy consumption and energy imports and has a significant impact on the functioning of the energy sector as a whole. Because transportation fuel consumption will account for most U.S. net energy imports through 2040 (as explained in Chapter 3 of the EIS), the United States has the potential to achieve large reductions in imported oil use and, consequently, in net energy imports during this time by improving the fuel efficiency of HD vehicles. Reducing dependence on energy imports is a key component of President Obama's May 29, 2014, *All-of-the-Above Energy Strategy*, which states that the development of HD Phase 2 standards "will lead to large savings in fuel, lower carbon dioxide (CO_2) emissions, and health benefits from reduced particulate matter and ozone."

Energy intensity measures the efficiency at which energy is converted to Gross Domestic Product (GDP), with a high value indicating an inefficient conversion of energy to GDP and a lower value indicating a more efficient conversion. From 2000 to 2011, the United States recorded substantial GDP growth with almost no increase in energy consumption because of reductions in energy intensity. The Annual Energy Outlook (AEO) forecasts ongoing declines in U.S. energy intensity, with average 2012–2040 GDP growth of 2.4 percent per year resulting in average annual total energy consumption growth of just 0.4 percent.

Although U.S. energy efficiency has been increasing and the U.S. share of global energy consumption has been declining in recent decades, total U.S. energy consumption has been increasing over that same period. Most of the increase in U.S. energy consumption over the past decades has not come from increased domestic energy production but instead from the increase in imports, largely for use in the transportation sector. Transportation fuel consumption has grown steadily on an annual basis.

Transportation is now the largest consumer of petroleum in the U.S. economy and a major contributor to U.S. net imports.

Petroleum is by far the largest source of energy used in the transportation sector. In 2011, petroleum supplied 92 percent of transportation energy demand, and in 2040, petroleum is expected to supply 87 percent of transportation energy demand. Consequently, transportation accounts for the largest share of total U.S. petroleum consumption. In 2011, the transportation sector accounted for 78 percent of total U.S. petroleum consumption. In 2040, transportation is expected to account for 73 percent of total U.S. petroleum consumption.

With petroleum expected to account for all U.S. net energy imports in 2040 and transportation expected to account for 73 percent of total petroleum consumption, U.S. net energy imports in 2040 are expected to result primarily from fuel consumption by light-duty and HD vehicles. The United States is poised to reverse the trend of the last 4 decades and achieve large reductions in net energy imports through 2040 due to continuing increases in U.S. energy efficiency and recent developments in U.S. energy production. Stronger fuel efficiency standards for HD vehicles have the potential to increase U.S. energy efficiency in the transportation sector further and reduce U.S. dependence on petroleum.

In the future, the transportation sector will continue to be the largest component of U.S. petroleum consumption and the second-largest component of total U.S. energy consumption, after the industrial sector. NHTSA's analysis of fuel consumption in this EIS assumes that fuel consumed by HD vehicles will consist predominantly of gasoline and diesel fuel derived from petroleum for the foreseeable future.

Key Findings for Energy Use

To calculate fuel savings for each action alternative, NHTSA subtracted projected fuel consumption under each action alternative from the level under the No Action Alternative. The fuel consumption and savings figures presented below are for 2019–2050 (2050 is the year by which nearly the entire U.S. HD vehicle fleet will most likely be composed of vehicles that are subject to the Phase 2 standards).

Direct and Indirect Impacts

As the alternatives increase in stringency, total fuel consumption decreases. Table S-2 shows total 2019–2050 fuel consumption for each alternative and the direct and indirect fuel savings for each action alternative compared with the No Action Alternative through 2050. This table reports total 2019–2050 fuel consumption in diesel gallon equivalents (DGE) for diesel, gasoline, natural gas (NG), and E85 fuel for HD pickups and vans (Classes 2b–3), vocational vehicles (Classes 2b–8), and tractor-trailers (Classes 7–8) for each alternative. Gasoline accounts for approximately 55 percent of HD pickup and van fuel use, 22 percent of vocational vehicle fuel use, and just 0.0001 percent of tractor-trailer fuel use. E85 accounts for less than 0.4 percent of HD pickup and van fuel use, and NG accounts for less than one percent of vocational vehicle fuel use. Diesel accounts for approximately 45 percent of HD pickup and van fuel use, 77 percent of vocational vehicle fuel use, and 100 percent of tractor trailer fuel use.

Table S-2. Direct and Indirect HD Vehicle Fuel Consumption and Fuel Savings Impacts by Alternative (billion DGE total for calendar years 2019–2050)

	Alt. 1 No Action	Alt. 2	Alt. 3 Preferred	Alt. 4	Alt. 5
Fuel Consumption					
HD Pickups and Vans	284.7	272.4	261.5	258.5	254.9
Vocational Vehicles	398.8	390.3	367.8	365.4	348.7
Tractor Trucks and Trailers	1,288.0	1,190.0	1,114.9	1,109.4	1,058.1
All HD Vehicles	**1,971.5**	**1,852.6**	**1,744.3**	**1,733.3**	**1,661.7**
Fuel Savings Impacts Compared with No Action Alternative					
HD Pickups and Vans	—	12.3	23.2	26.2	29.8
Vocational Vehicles	—	8.6	31.0	33.5	50.2
Tractor Trucks and Trailers	—	98.0	173.1	178.5	229.9
All HD Vehicles	**—**	**118.9**	**227.3**	**238.2**	**309.9**

Total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative is projected to amount to 1,971.5 billion DGE. Total projected 2019–2050 fuel consumption decreases across action alternatives, from 1,852.6 billion DGE under Alternative 2 to 1,661.7 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 direct and indirect fuel savings ranging from 118.9 billion DGE under Alternative 2 to 309.9 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1,744.3 billion DGE, and direct and indirect fuel savings compared with the No Action Alternative would be 227.3 billion DGE.

Cumulative Impacts

As with direct and indirect impacts, fuel consumption under each action alternative would decrease with increasing stringency under the cumulative impacts analysis, which incorporates other past, present, and reasonably foreseeable future actions that would lead to improvements in HD vehicle fuel efficiency. Table S-3 shows total 2019–2050 fuel consumption for each alternative and the cumulative fuel savings for each action alternative compared with the No Action Alternative through 2050. Total 2019–2050 fuel consumption for each action alternative in this table is the same as shown for the corresponding action alternative in Table S-2. The No Action Alternative's fuel consumption is higher in Table S-3 than in Table S-2 because the No Action Alternative's fuel consumption in Table S-3 generally does not reflect forecast improvements in the average fuel efficiency of new HD vehicles MYs 2018 and beyond due to market forces. The cumulative impact fuel savings resulting from each action alternative are higher in Table S-3 than the direct and indirect impact fuel savings reported in Table S-2 because the fuel savings in Table S-3 reflect the cumulative impact of market-based incentives for improving fuel efficiency after 2018, plus the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

Table S-3. Cumulative HD Vehicle Fuel Consumption and Fuel Savings Impacts by Alternative (billion DGE total for calendar years 2014–2050)

	Alt. 1 No Action	Alt. 2	Alt. 3 Preferred	Alt. 4	Alt. 5
Fuel Consumption					
HD Pickups and Vans	288.0	272.4	261.5	258.5	254.9
Vocational Vehicles	398.8	390.3	367.8	365.4	348.7
Tractor Trucks and Trailers	1,304.9	1,190.0	1,114.9	1,109.4	1,058.1
All HD Vehicles	**1,991.7**	**1,852.6**	**1,744.3**	**1,733.3**	**1,661.7**
Fuel Savings Impacts Compared with No Action Alternative					
HD Pickups and Vans	—	15.6	26.5	29.5	33.1
Vocational Vehicles	—	8.6	31.0	33.5	50.2
Tractor Trucks and Trailers	—	114.9	190.0	195.4	246.8
All HD Trucks	**—**	**139.1**	**247.5**	**258.4**	**330.1**

Total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative in Table S-3 is projected to amount to 1,991.7 billion DGE. Total 2019–2050 projected fuel consumption decreases across alternatives, from 1,852.6 billion DGE under Alternative 2 to 1,661.7 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 cumulative fuel savings ranging from 139.1 billion DGE under Alternative 2 to 330.1 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1,744.3 billion DGE, and cumulative fuel savings compared with the No Action Alternative would be 247.5 billion DGE.

Air Quality

Air pollution and air quality can affect public health, public welfare, and the environment. The Proposed Action and alternatives under consideration would affect air pollutant emissions and air quality. The EIS air quality analysis assesses the impacts of the alternatives in relation to emissions of pollutants of concern from mobile sources, the resulting impacts on human health, and the monetized health benefits of emissions reductions. Although air pollutant emissions generally decline under the action alternatives compared with the No Action Alternative, the magnitudes of the declines are not consistent across all pollutants (and some air pollutant emissions might increase). This inconsistency reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies NHTSA assumes manufacturers will incorporate to comply with the standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in vehicle miles traveled (VMT).

Under the authority of the Clean Air Act and its amendments, EPA has established National Ambient Air Quality Standards (NAAQS) for six relatively common air pollutants, known as “criteria” pollutants because EPA regulates them by developing human health-based or environmentally based criteria for setting permissible levels. The criteria pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), ozone, sulfur dioxide (SO_2), lead, and particulate matter (PM) with an aerodynamic diameter equal to or less than 10 microns (PM10) and 2.5 microns (PM2.5, or fine particles). Ozone is not emitted directly from vehicles but is formed from emissions of ozone precursor pollutants such as nitrogen oxides (NO_X) and volatile organic compounds (VOCs).

In addition to criteria pollutants, motor vehicles emit some substances defined by the 1990 Clean Air Act amendments as hazardous air pollutants. Hazardous air pollutants include certain VOCs, compounds in PM, pesticides, herbicides, and radionuclides that present tangible hazards based on scientific studies of human (and other mammal) exposure. Hazardous air pollutants from vehicles are known as mobile-source air toxics (MSATs). The MSATs included in this analysis are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter (DPM), and formaldehyde. EPA and the Federal Highway Administration have identified these air toxics as the MSATs that typically are of greatest concern when analyzing impacts of highway vehicles. DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the PM2.5 particle-size class.

Health Effects of the Pollutants

The criteria pollutants assessed in the EIS have been shown to cause a range of adverse health effects at various concentrations and exposures, including:

- Damage to lung tissue
- Reduced lung function
- Exacerbation of existing respiratory and cardiovascular diseases
- Difficulty breathing
- Irritation of the upper respiratory tract
- Bronchitis and pneumonia
- Reduced resistance to respiratory infections
- Alterations to the body's defense systems against foreign materials
- Reduced delivery of oxygen to the body's organs and tissues
- Impairment of the brain's ability to function properly
- Cancer and premature death

MSATs are also associated with adverse health effects. For example, EPA classifies acetaldehyde, benzene, 1,3-butadiene, formaldehyde, and certain components of DPM as either known or probable human carcinogens. Many MSATs are also associated with non-cancer health effects, such as respiratory irritation.

Contribution of U.S. Transportation Sector to Air Pollutant Emissions

The U.S. transportation sector is a major source of emissions of certain criteria pollutants or their chemical precursors. Emissions of these pollutants from on-road mobile sources have declined dramatically since 1970 as a result of pollution controls on vehicles and regulation of the chemical content of fuels. Nevertheless, the U.S. transportation sector remains a major source of emissions of certain criteria pollutants or their chemical precursors. On-road mobile sources (i.e., highway vehicles, including vehicles covered by the proposed rule) are responsible for 24,796,000 tons per year of CO (34 percent of total U.S. emissions), 185,000 tons per year (3 percent) of PM2.5 emissions, and 268,000 tons per year (1 percent) of PM10 emissions. HD vehicles contribute 6 percent of U.S. highway emissions of CO, 66 percent of highway emissions of PM2.5, and 55 percent of highway emissions of PM10. Almost all of the PM in motor vehicle exhaust is PM2.5; therefore, this analysis focuses on PM2.5 rather than PM10. On-road mobile sources also contribute 2,161,000 tons per year (12 percent of total nationwide emissions) of VOCs and 5,010,000 tons per year (38 percent) of NO_X emissions, which are

chemical precursors of ozone. HD vehicles contribute 8 percent of U.S. highway emissions of VOCs and 50 percent of NO_X. In addition, NO_X is a PM2.5 precursor, and VOCs can be PM2.5 precursors. SO_2 and other oxides of sulfur (SO_X) are important because they contribute to the formation of PM2.5 in the atmosphere; however, on-road mobile sources account for less than 0.56 percent of U.S. SO_2 emissions. With the elimination of lead in automotive gasoline, lead is no longer emitted from motor vehicles in more than negligible quantities and is therefore not assessed in this analysis.

Methodology

To analyze air quality and human health impacts, NHTSA calculated the emissions of criteria pollutants and MSATs from HD vehicles that would occur under each alternative. NHTSA then estimated the resulting changes in emissions under each action alternative by comparing emissions under that alternative to those under the No Action Alternative. The resulting changes in air quality and effects on human health were assumed to be proportional to the changes in emissions projected to occur under each action alternative.

The air quality results, including impacts on human health, are based on a number of assumptions about the type and rate of emissions from the combustion of fossil fuels. In addition to tailpipe emissions, this analysis accounts for upstream emissions from the production and distribution of fuels. To estimate Classes 2b –3 upstream emissions changes resulting from the decreased downstream fuel consumption, the analysis uses the Volpe HD model, which incorporates emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (2013 version developed by the U.S. Department of Energy Argonne National Laboratory). The Volpe HD model uses the decreased volumes of the fuels along with the emissions factors from GREET for the various fuel production and transport processes to estimate the net changes in upstream emissions as a result of fuel consumption changes. To estimate Classes 4–8 upstream emissions, the analysis uses a spreadsheet model developed by EPA that uses an identical methodology based on GREET emissions factors.

Key Findings for Air Quality

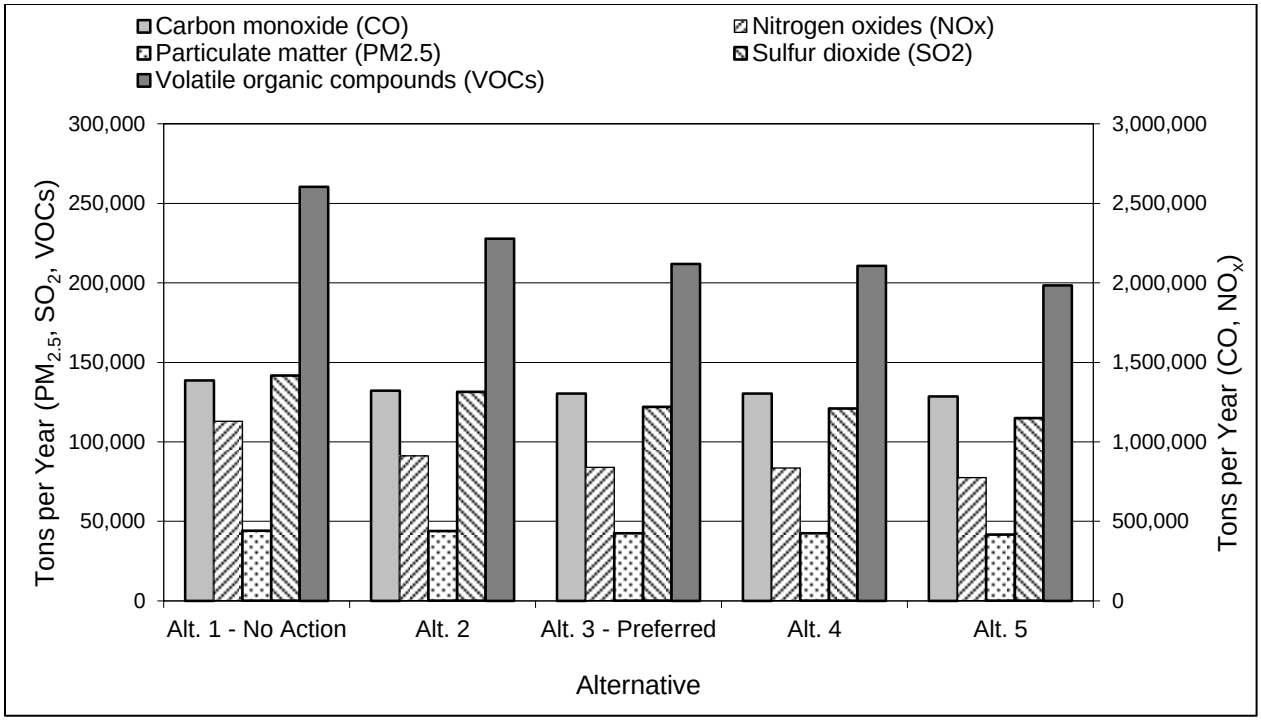
The findings for air quality effects are shown for 2035 in this summary, a mid-term forecast year by which time a large proportion of HD vehicle VMT would be accounted for by vehicles that meet the proposed standards. The EIS provides findings for air quality effects for 2018, 2025, 2035, and 2050. In general, emissions of criteria air pollutants decrease with increased stringency across alternatives, with few exceptions. The changes in emissions reflect the complex interactions among the tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the proposed standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in VMT. To estimate the reduced incidence of PM2.5-related adverse health effects and the associated monetized health benefits from the emissions reductions, NHTSA multiplied direct PM2.5 and PM2.5 precursor (NO_X, SO_2, and VOCs) emissions reductions by EPA-provided pollutant-specific benefit-per-ton estimates. Reductions in adverse health outcomes include reduced incidences of premature mortality, chronic bronchitis, respiratory emergency room visits, and work-loss days.

Direct and Indirect Impacts

Criteria Pollutants

- Emissions of criteria pollutants are highest under the No Action Alternative; they decline as fuel consumption decreases from the least stringent action alternative (Alternative 2) to the most stringent alternative (Alternative 5), as shown in Figure S-2. Many of the emissions changes are relatively small, especially for CO and PM2.5, which were reduced by less than 9 percent under all alternatives.
- Emissions reductions were greatest under Alternative 5 for all criteria pollutants. By 2050 these reductions ranged from 6 percent for PM2.5 to 37 percent for NO_x.
- Under the Preferred Alternative, emissions of all criteria pollutants are reduced compared to emissions under the No Action Alternative. By 2050 these reductions ranged from 4 percent for PM2.5 to 31 percent for NO_x.

Figure S-2. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2035 by Alternative, Direct and Indirect Impacts

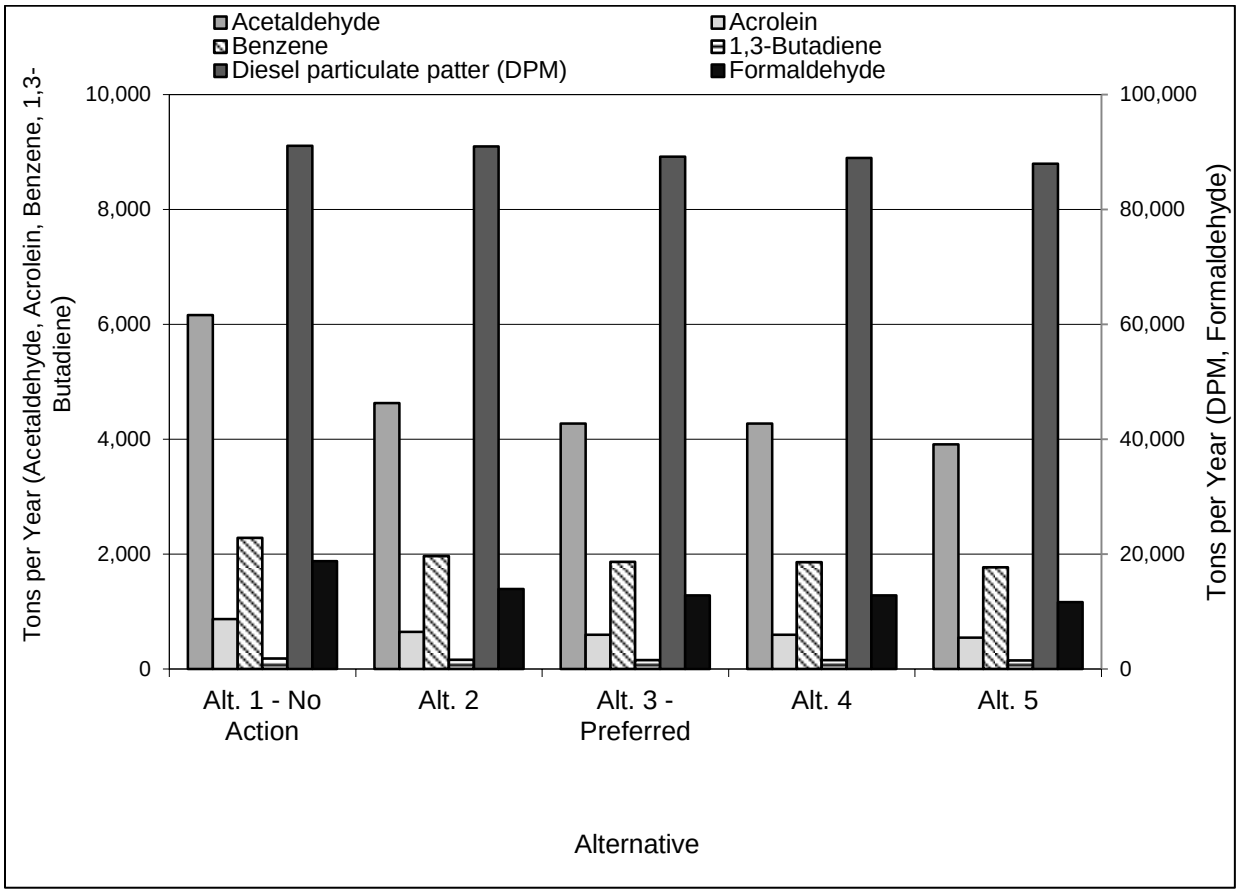


Hazardous Air Pollutants

- Emissions of MSATs are highest under the No Action Alternative; they decline as fuel consumption decreases from the least stringent action alternative (Alternative 2) to the most stringent alternative (Alternative 5), as shown in Figure S-3. Many of the emissions changes are relatively small, especially for DPM, which was reduced by less than 4 percent under all alternatives.
- Emissions reductions were greatest under Alternative 5 for all MSATs. By 2050 these reductions ranged from 4 percent for DPM to 44 percent for formaldehyde.
- Under the Preferred Alternative, emissions of all MSATs are reduced compared to emissions under the No Action Alternative. By 2050, emissions of DPM were reduced by approximately 3 percent,

emissions of 1,3-butadiene by 17 percent, emissions of benzene by 22 percent, emissions of acetaldehyde by 36 percent, and emissions of acrolein and formaldehyde by 37 percent.

Figure S-3. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2035 by Alternative, Direct and Indirect Impacts



Health and Monetized Health Benefits

- All action alternatives would generally result in reduced adverse health effects (mortality, chronic bronchitis, emergency room visits for asthma, and work-loss days) nationwide compared with the No Action Alternative, with increasing reductions from the least stringent (Alternative 2) to the most stringent (Alternative 5) alternatives.
- Because monetized health benefits increase with reductions in adverse health effects, monetized benefits increase across alternatives along with increasing HD vehicle fuel efficiency standards. When estimating quantified and monetized health impacts, EPA relies on results from two PM2.5-related premature mortality studies it considers equivalent: Krewski et al. (2009) and Lepeule et al. (2012). EPA recommends that monetized benefits be shown by using incidence estimates derived from each of these studies and valued using a 3 percent and a 7 percent discount rate to account for an assumed lag in the occurrence of mortality after exposure, for a total of four separate calculations of monetized health benefits. Using these four calculations, estimated monetized health benefits in 2035 range from $3.1 to $17.5 billion under all action alternatives.
- Estimated monetized health benefits in 2035 range from $3.1 to $7.8 billion under Alternative 2, $5.3 to $13.3 billion under the Preferred Alternative, $5.5 to $13.8 billion under Alternative 4, and $6.9 to $17.5 billion under Alternative 5.

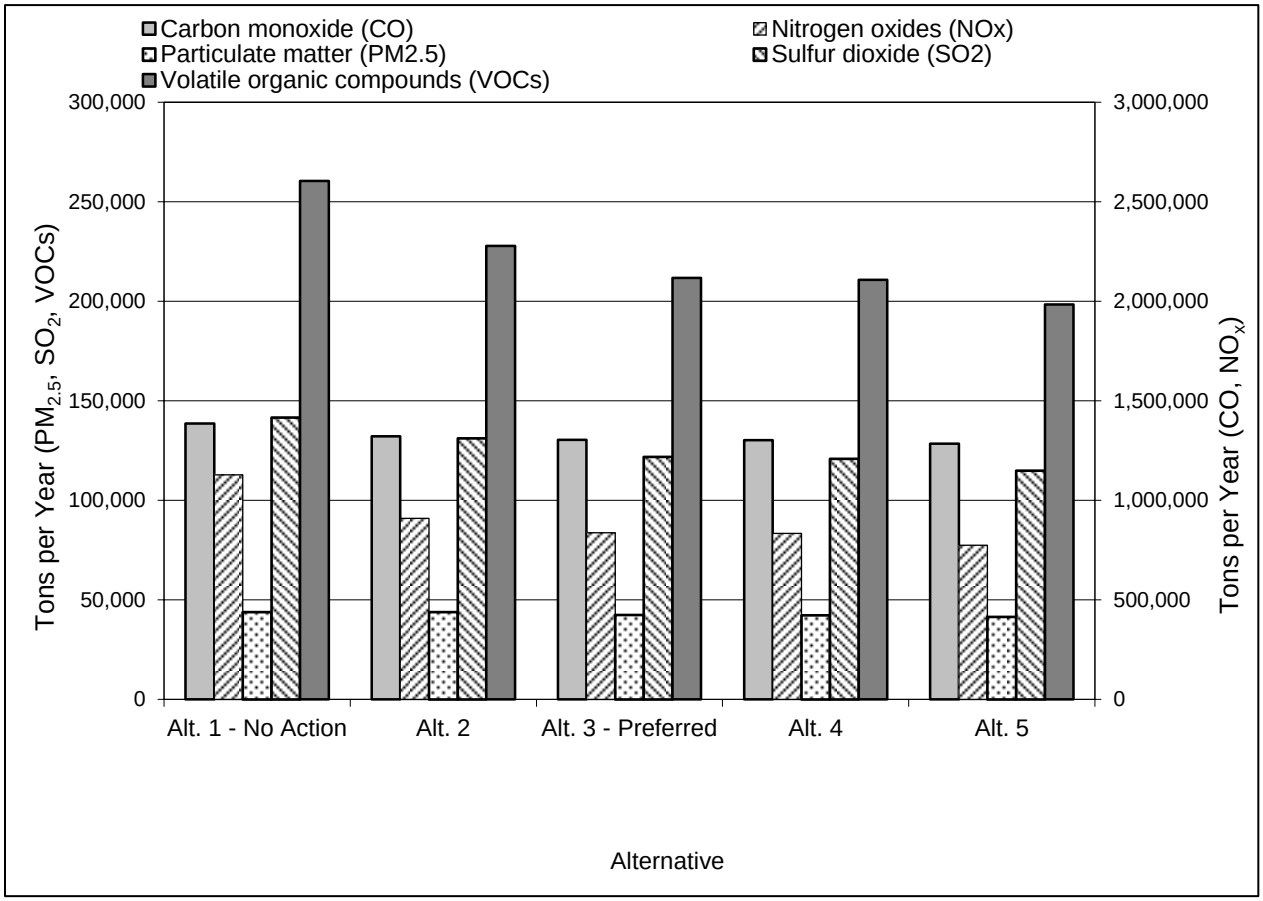
See Section 4.2.1 of this EIS for data on the direct effects of criteria and hazardous air pollutant emissions and the monetized health benefits for the alternatives.

Cumulative Impacts

Criteria Pollutants

- Cumulative emissions of criteria pollutants are highest under the No Action Alternative; they decline as fuel consumption decreases across the action alternatives, as shown in Figure S-4. Many of the emissions changes are relatively small, especially for CO and PM2.5, which were reduced by 9 percent or less under all alternatives.
- Emissions reductions were greatest under Alternative 5 for all criteria pollutants. By 2050 these reductions ranged from 7 percent for PM2.5 to 38 percent for NO_x.
- Under the Preferred Alternative, emissions of all criteria pollutants are reduced compared to emissions under the No Action Alternative. By 2050 these reductions ranged from 5 percent for PM2.5 to 32 percent for NO_x.

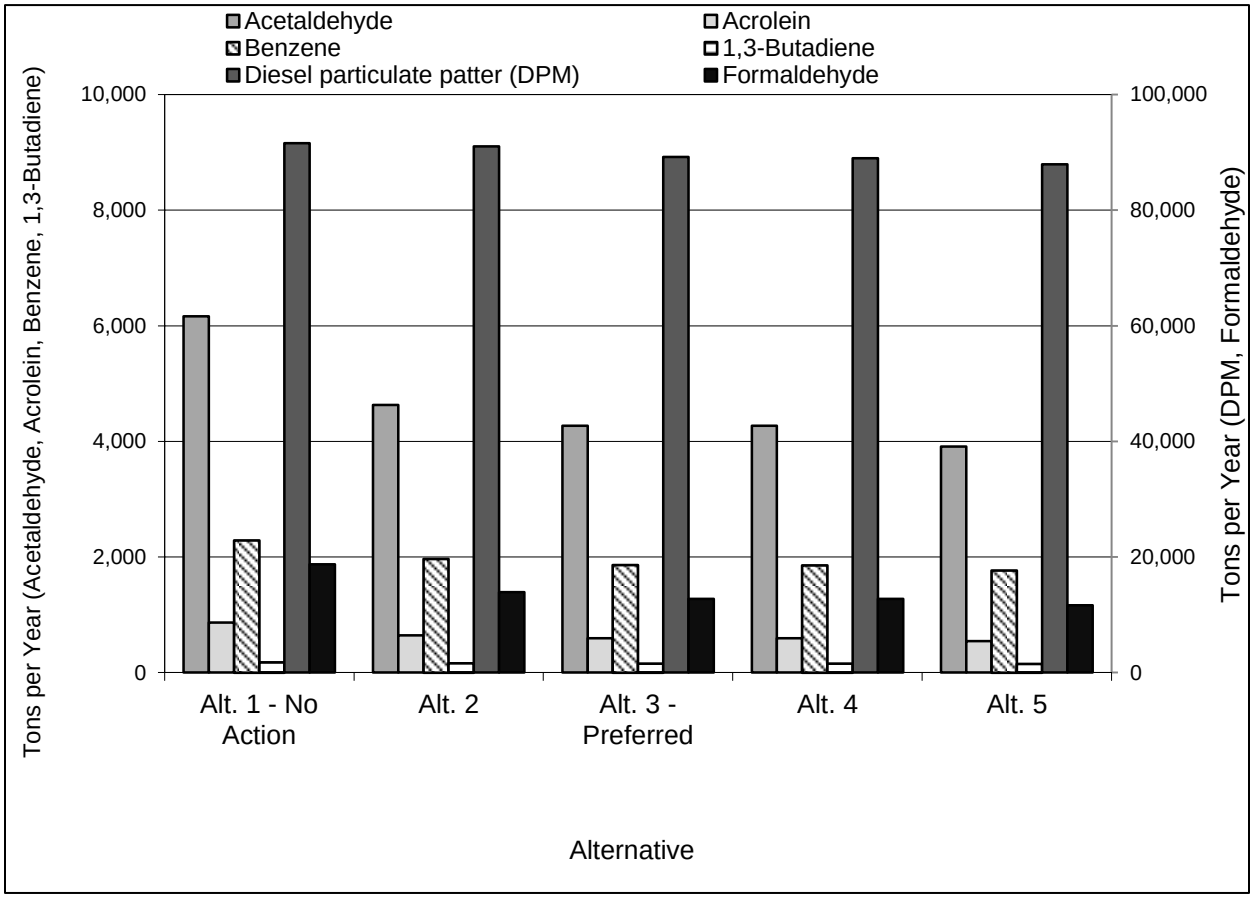
Figure S-4. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2035 by Alternative, Cumulative Impacts



Hazardous Air Pollutants

- Emissions of MSATs are highest under the No Action Alternative; they generally decline as fuel consumption decreases from the least stringent action alternative (Alternative 2) to the most stringent alternative (Alternative 5), as shown in Figure S-5. Many of the emissions changes are relatively small, especially for DPM, which were reduced by less than 5 percent under all alternatives.
- Emissions reductions were greatest under Alternative 5 for all MSATs. By 2050 these reductions ranged from 5 percent for DPM to 44 percent for formaldehyde.
- Under the Preferred Alternative, emissions of all MSATs are reduced compared to emissions under the No Action Alternative. By 2050, emissions of DPM were reduced by approximately 3 percent, emissions of 1,3-butadiene by 18 percent, emissions of benzene by 23 percent, emissions of acetaldehyde by 36 percent, and emissions of acrolein and formaldehyde by 37 percent.

Figure S-5. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2035 by Alternative, Cumulative Impacts



Health and Monetized Health Benefits

- All action alternatives would generally result in reduced adverse health effects (mortality, chronic bronchitis, emergency room visits for asthma, and work-loss days) nationwide compared with the No Action Alternative.
- Estimated monetized health benefits in 2035 range from $3.5 to $18.5 billion for all alternatives.
- Estimated monetized health benefits in 2035 range from $3.5 to $8.9 billion under Alternative 2, $5.7 to $14.3 billion under the Preferred Alternative, $5.9 to $14.8 billion under Alternative 4, and $7.4 to $18.5 billion under Alternative 5.

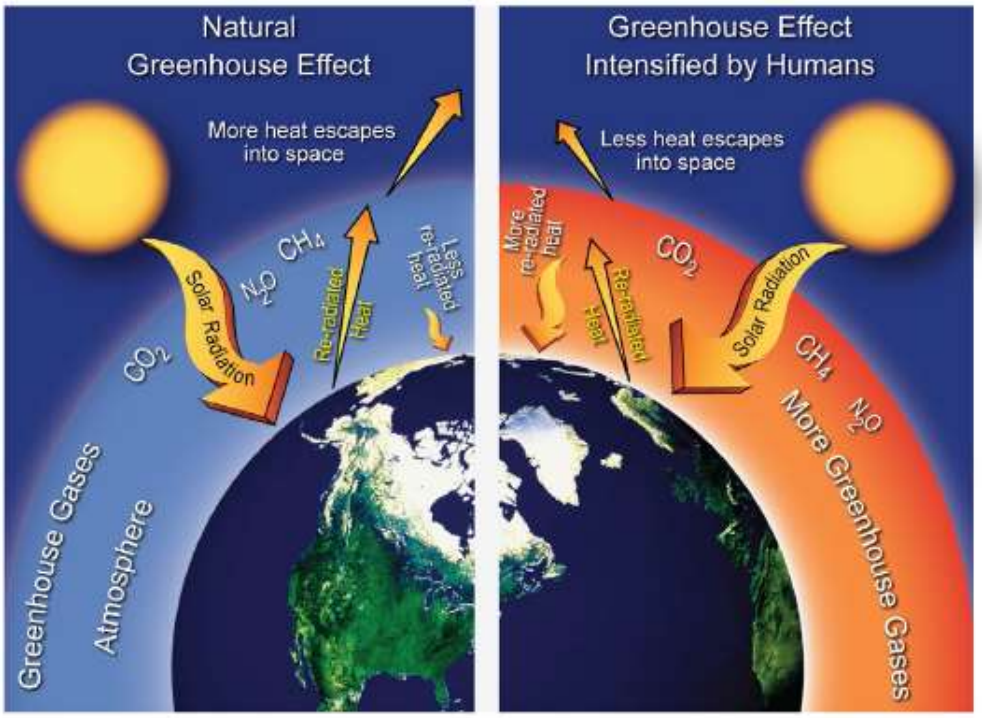
See Section 4.2.2 of this EIS for cumulative effects data on criteria and hazardous air pollutant emissions and the monetized health benefits for the alternatives.

Climate

Earth absorbs heat energy from the sun and returns most of this heat to space as terrestrial infrared radiation. GHGs trap heat in the lower atmosphere (the atmosphere extending from Earth's surface to approximately 4 to 12 miles above the surface) by absorbing heat energy emitted by Earth's surface and lower atmosphere, and reradiating much of it back to Earth's surface, thereby causing warming. This

process, known as the *greenhouse effect*, is responsible for maintaining surface temperatures that are warm enough to sustain life. Most GHGs, including CO_2, methane (CH_4), nitrous oxide (N_2O), water vapor, and ozone, occur naturally. Human activities, particularly fossil-fuel combustion, lead to the presence of increased concentrations of GHGs in the atmosphere, thereby intensifying the warming associated with the Earth's greenhouse effect (*see* Figure S-6).

Figure S-6. Human Influence on the Greenhouse Effect



Source: GCRP (U.S. Global Change Research Program) 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. Washington, DC.

Since the industrial revolution, when fossil fuels began to be burned in increasing quantities, concentrations of GHGs in the atmosphere have increased. CO_2 atmospheric concentrations have increased by more than 40 percent since pre-industrial times, while the concentration of CH_4 is now 150 percent above pre-industrial levels. This buildup of GHGs in the atmosphere is changing the Earth's energy balance and causing the planet to warm, which in turn affects sea levels, precipitation patterns, cloud cover, ocean temperatures and currents, and other climatic conditions. Scientists refer to this phenomenon as "global climate change."

During the past century, Earth's surface temperature has risen by approximately 0.8 degree Celsius (°C) (1.4 degrees Fahrenheit [°F]), and sea levels have risen 19 centimeters (7.5 inches), with a rate of increase of approximately 3.2 millimeters (0.13 inch) per year from 1993 to 2010. These observed changes in the global climate are largely a result of GHG emissions from human activities. The United Nations Environment Programme and the World Meteorological Organization established Intergovernmental Panel on Climate Change (IPCC) has concluded that "[H]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea-level rise, and in changes in some climate extremes…It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century."

Throughout this EIS, NHTSA has relied extensively on findings of the IPCC, U.S. Climate Change Science Program (CCSP), National Research Council (NRC), Arctic Council, U.S. Global Change Research Program (GCRP), and EPA. This discussion focuses heavily on the most recent thoroughly peer-reviewed and credible assessments of global and U.S. climate change. *See* Section 5.1 of this EIS for more detail.

Impacts of Climate Change

Climate change is expected to have a wide range of effects on temperature, sea level, precipitation patterns, and severe weather events, which in turn could affect human health and safety, infrastructure, food and water supplies, and natural ecosystems, for example:

- Impacts on freshwater resources could include changes in water demand such as significant increases in irrigation needs, water shortages, general variability in water supply, and increasing flood risk in response to flooding, drought, changes in snowpack and the timing of snow melt, changes in weather patterns, and saltwater intrusions from sea-level rise.
- Impacts on terrestrial and freshwater ecosystems could include shifts in the range and seasonal migration patterns of species, relative timing of species' life-cycle events, potential extinction of sensitive species that are unable to adapt to changing conditions, increases in the occurrence of forest fires and pest infestations, and changes in habitat productivity due to increased atmospheric concentrations of CO_2.
- Impacts on ocean systems, coastal, and low-lying areas could include the loss of coastal areas due to submersion and/or erosion, reduction in coral reefs and other key habitats thereby affecting the distribution, abundance, and productivity of many marine species, increased vulnerability of the built environment and associated economies to severe weather and storm surges, and increased salinization of estuaries and freshwater aquifers.
- Impacts on food, fiber, and forestry could include increasing tree mortality, forest ecosystem vulnerability, productivity losses in crops and livestock, and changes in the nutritional quality of pastures and grazelands in response to fire, insect infestations, increases in weeds, drought, disease outbreaks, and/or extreme weather events. Many marine fish species may migrate to deeper and/or colder water in response to rising ocean temperatures. Impacts on food, including yields, food processing, storage, and transportation, may affect food prices and food security globally.
- Impacts on rural and urban areas could include affecting water and energy supplies, wastewater and stormwater systems, transportation, telecommunications, provision of social services, agricultural incomes, and air quality. The impacts may be greater for vulnerable populations such as lower-income populations, the elderly, those with existing health conditions, and young children.
- Impacts on human health could include increased mortality and morbidity due to excessive heat, increases in respiratory conditions due to poor air quality and aeroallergens, increases in water and food-borne diseases, changes in the seasonal patterns of vector-borne diseases, and increases in malnutrition. The most disadvantaged groups such as children, elderly, sick, and low-income populations are especially vulnerable.
- Impacts on human security could include increased threats in response to adversely affected livelihoods, compromised cultures, increased and/or restricted migration, increased risk of armed conflicts, reduction in providing adequate essential services such as water and energy, and increased geopolitical rivalry.

Climate change has been projected to have a direct impact on stratospheric ozone recovery, although there are large elements of uncertainty within these projections.

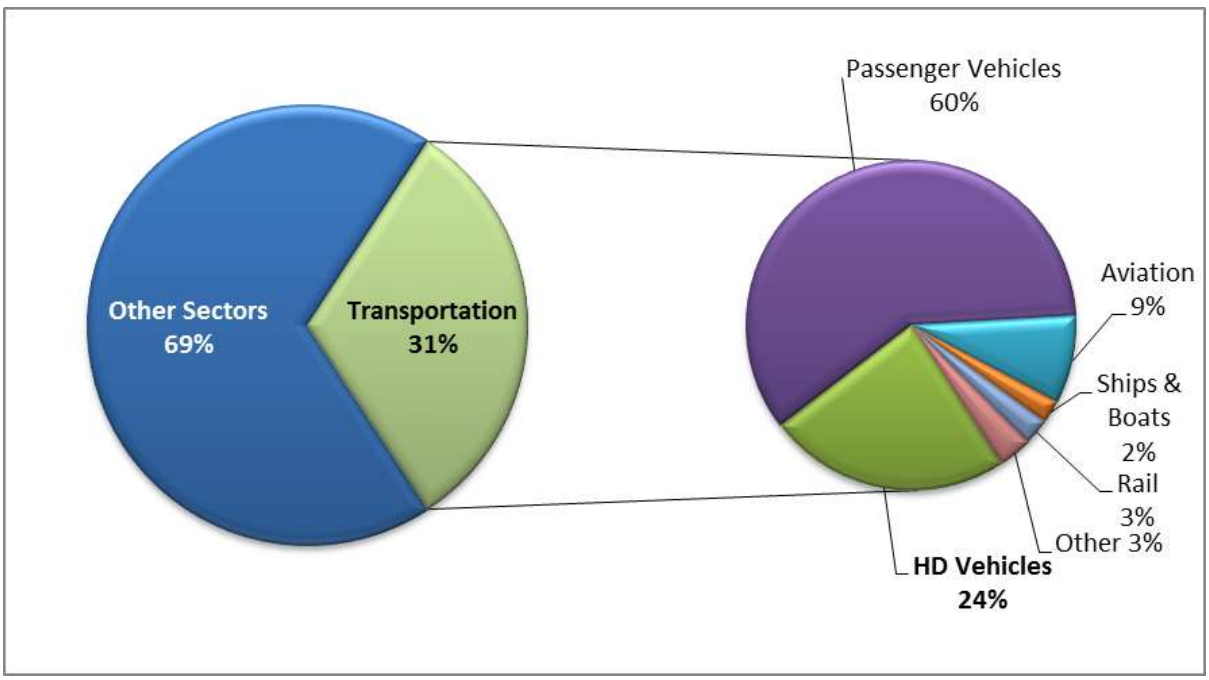
In addition to its role as a GHG in the atmosphere, CO_2 is transferred from the atmosphere to water, plants, and soil. In water, CO_2 combines with water molecules to form carbonic acid. When CO_2 dissolves in seawater, a series of well-known chemical reactions begins that increases the concentration of hydrogen ions and makes seawater more acidic, which adversely affects corals and other marine life.

Increased concentrations of CO_2 in the atmosphere can also stimulate plant growth to some degree, a phenomenon known as the CO_2 fertilization effect. The available evidence indicates that different plants respond in different ways to enhanced CO_2 concentrations under varying climatic conditions.

Contribution of the U.S. Transportation Sector to U.S. and Global CO_2 Emissions

Contributions to the buildup of CO_2 and other GHGs in the atmosphere vary greatly from country to country and depend heavily on the level of industrial and economic activity. Emissions from the United States account for approximately 16.5 percent of total global CO_2 emissions (according to the World Resources Institute's Climate Analysis Indicators Tool). As shown in Figure S-7, the U.S. transportation sector accounted for 31 percent of total U.S. CO_2 emissions in 2013, with HD vehicles accounting for 24 percent of total U.S. CO_2 emissions from transportation. Therefore, approximately 7.5 percent of total U.S. CO_2 emissions were from HD vehicles. These U.S. HD vehicles account for 1.2 percent of total global CO_2 emissions, based on the comprehensive global CO_2 emissions data available for 2011 (WRI 2015).

Figure S-7. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2013



Source: U.S. Environmental Protection Agency. 2015.

Key Findings for Climate

The action alternatives would decrease the growth in global GHG emissions compared with the No Action Alternative, resulting in reductions in the anticipated increases in CO_2 concentrations, temperature, precipitation, and sea level that would otherwise occur. They would also, to a small degree, reduce the impacts and risks of climate change.

Under the No Action Alternative, total CO_2 emissions from HD vehicles in the United States will increase substantially between 2018 and 2100.[2] Growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use, is projected to result in growth in VMT. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles.

NHTSA estimates that the action alternatives will reduce fuel consumption and CO_2 emissions compared with what they would be in the absence of the standards (i.e., fuel consumption and CO_2 emissions under the No Action Alternative) (*see* Figure S-8).

The global emissions scenario used in the cumulative effects analysis (and described in Chapter 5 of this EIS) differs from the global emissions scenario used for climate change modeling of direct and indirect effects. In the cumulative effects analysis, the Reference Case global emissions scenario used in the climate modeling analysis reflects reasonably foreseeable actions in global climate change policy; in contrast, the global emissions scenario used for the analysis of direct and indirect effects assumes that no significant global controls on GHG emissions will be adopted. *See* Section 5.3.3.3.2 of the EIS for more explanation of the cumulative effects methodology.

Estimates of GHG emissions and reductions (direct and indirect impacts and cumulative impacts) are presented below for each of the five alternatives. Key climate effects, such as mean global increase in surface temperature and sea-level rise, which result from changes in GHG emissions, are also presented for each of the five alternatives. These effects are typically modeled to 2100 or longer because of the amount of time required for the climate system to show the effects of the GHG emissions reductions. This inertia reflects primarily the amount of time required for the ocean to warm in response to increased radiative forcing.

The impacts of the action alternatives on global mean surface temperature, precipitation, or sea-level rise are small in relation to the expected changes associated with the emissions trajectories that assume that no significant global controls on GHG emissions are adopted. This is because of the global and multi-sectoral nature of the climate problem. Although these effects are small, they occur on a global scale and are long lasting; therefore, in aggregate, they can have large consequences for health and welfare and can make an important contribution to reducing the risks associated with climate change.

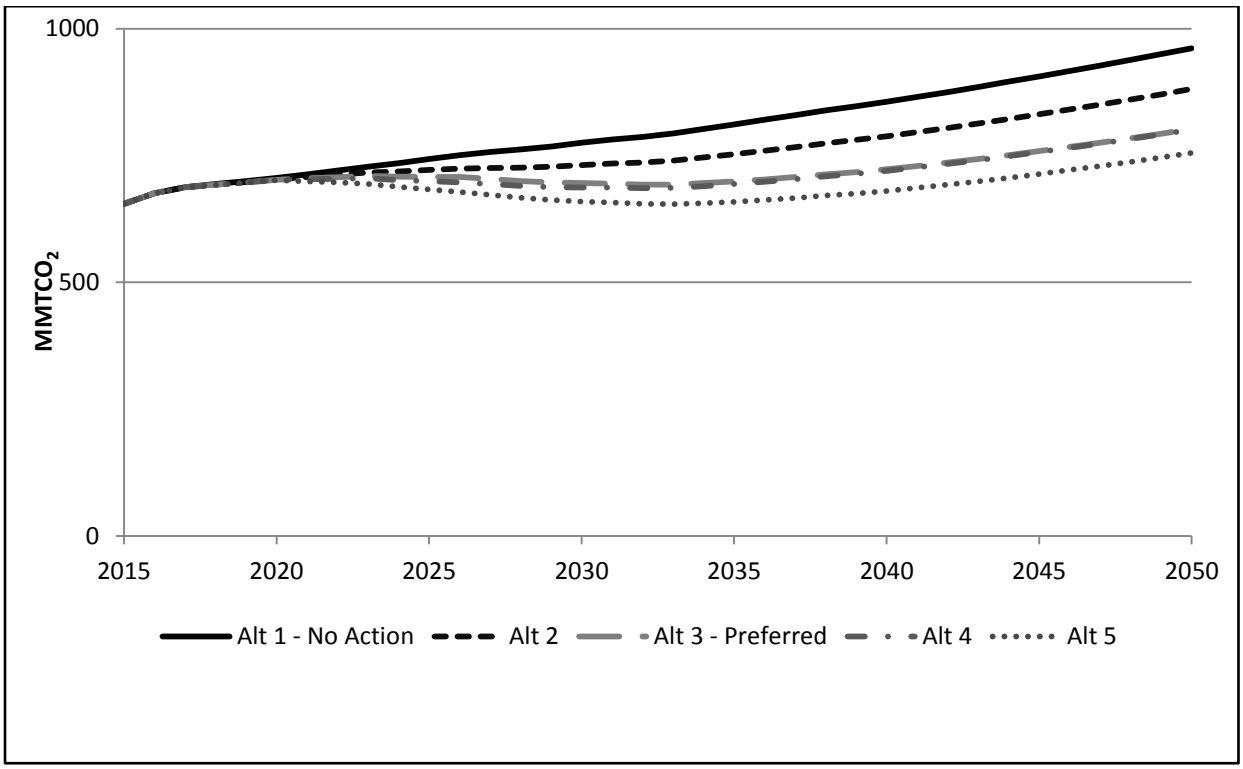
[2] Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use—more than 95 percent, even after accounting for the higher GWPs of other GHGs— NHTSA's consideration of GHG impacts focuses on reductions in CO2 emissions expected under the action alternatives.

Direct and Indirect Impacts

Greenhouse Gas Emissions

- HD vehicles are projected to emit 73,600 million metric tons of carbon dioxide ($MMTCO_2$) in the period 2018–2100 under the No Action Alternative. Alternative 2 would reduce these emissions by 7 percent by 2100, the Preferred Alternative by 15 percent, Alternative 4 by 15 percent, and Alternative 5 by 19 percent. Figure S-8 shows projected annual CO_2 emissions from HD vehicles under each alternative. As shown in the figure, emissions are highest under the No Action Alternative, while Alternatives 2 through 5 show increasing reductions in emissions compared with emissions under the No Action Alternative.
- Compared with total projected U.S. emissions of 884 $MMTCO_2$ under the No Action Alternative in 2100, the action alternatives are expected to reduce U.S. CO_2 emissions in 2100 by 8 percent under Alternative 2, 17 percent under the Preferred Alternative, 17 percent under Alternative 4, and 21 percent under Alternative 5.
- Compared with total global CO_2 emissions from all sources of 5,063,078 $MMTCO_2$ under the No Action Alternative from 2018 through 2100, the action alternatives are expected to reduce global CO_2 emissions between 0.1 and 0.3 percent by 2100.
- The emissions reductions in 2025 under each of the action alternatives compared with emissions under the No Action Alternative are approximately equivalent to the annual emissions from 0.7 million HD vehicles under Alternative 2, 1.1 million HD vehicles under the Preferred Alternative, 1.4 million HD vehicles under Alternative 4, and 1.9 million HD vehicles under Alternative 5.

Figure S-8. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative, Direct and Indirect Impacts

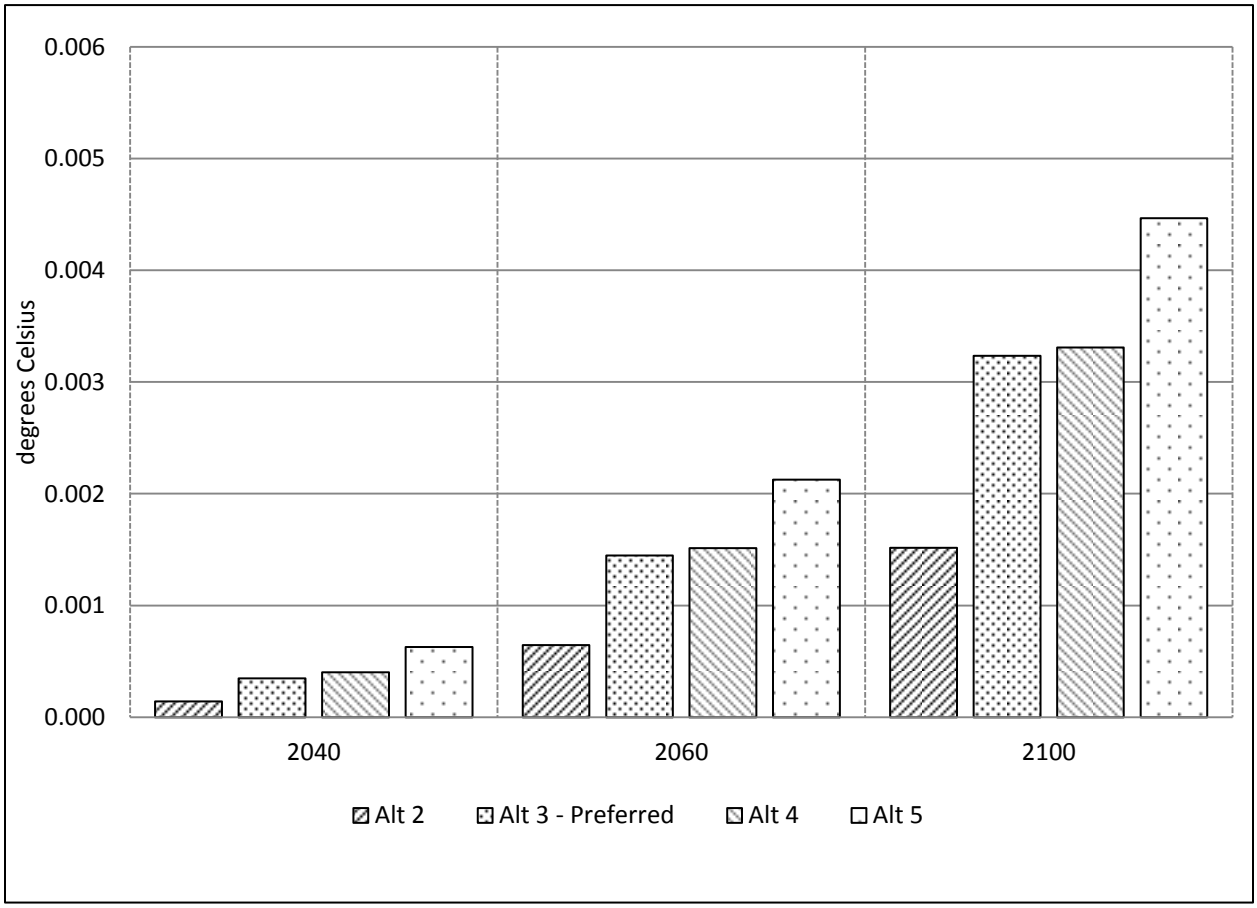


CO_2 Concentration, Global Mean Surface Temperature, Sea-Level Rise, and Precipitation

CO_2 emissions affect the concentration of CO_2 in the atmosphere, which in turn, affects global temperature, sea level, and precipitation patterns. For the analysis of direct and indirect effects, NHTSA used the Global Change Assessment Model Reference scenario (*see* Section 5.3.3.3.1 of this EIS for more details) to represent the Reference Case emissions scenario (i.e., future global emissions assuming no additional climate policy). The impacts of the Proposed Action and alternatives on temperature, precipitation, or sea-level rise are small in absolute terms because the action alternatives result in a small proportional change to the emissions trajectories in the Reference Case scenario to which the alternatives were compared. Although these effects are small, they occur on a global scale and are long lasting; therefore, they can make an important contribution to reducing the risks associated with climate change.

- Estimated CO_2 concentrations in the atmosphere for 2100 would range from 787.9 parts per million (ppm) under Alternative 5 to approximately 789.1 ppm under the No Action Alternative, indicating a maximum atmospheric CO_2 reduction of approximately 1.2 ppm compared to the No Action Alternative. The Preferred Alternative would reduce global CO_2 concentrations by approximately 0.9 ppm from CO_2 concentrations under the No Action Alternative.
- Global mean surface temperature is anticipated to increase by approximately 3.48°C (6.27°F) under the No Action Alternative by 2100. Implementing the most stringent alternative (Alternative 5) would reduce this projected temperature increase by 0.004°C (0.008°F), while implementing the least stringent alternative (Alternative 2) would reduce projected temperature increase by up to 0.002°C (0.003°F). Falling between these two levels, the Preferred Alternative would decrease projected temperature increase under the No Action Alternative by 0.003°C (0.006°F). Figure S-9 shows the reduction in projected global mean surface temperature under each action alternative compared with temperatures under the No Action Alternative.
- Projected sea-level rise in 2100 ranges from a high of 76.28 centimeters (30.03 inches) under the No Action Alternative to a low of 76.20 centimeters (30.00 inches) under Alternative 5. Therefore, the most stringent alternative would result in a maximum reduction in sea-level rise equal to 0.09 centimeter (0.03 inch) by 2100 compared with the level projected under the No Action Alternative. Sea-level rise under the Preferred Alternative would be reduced by 0.06 centimeter (0.02 inch) compared with the No Action Alternative.
- Global mean precipitation is anticipated to increase by 5.85 percent by 2100 under the No Action Alternative. Under the action alternatives, this increase in precipitation would be reduced by less than 0.01 percent.

Figure S-9. Reduction in Global Mean Surface Temperature Compared with the No Action Alternative, Direct and Indirect Impacts

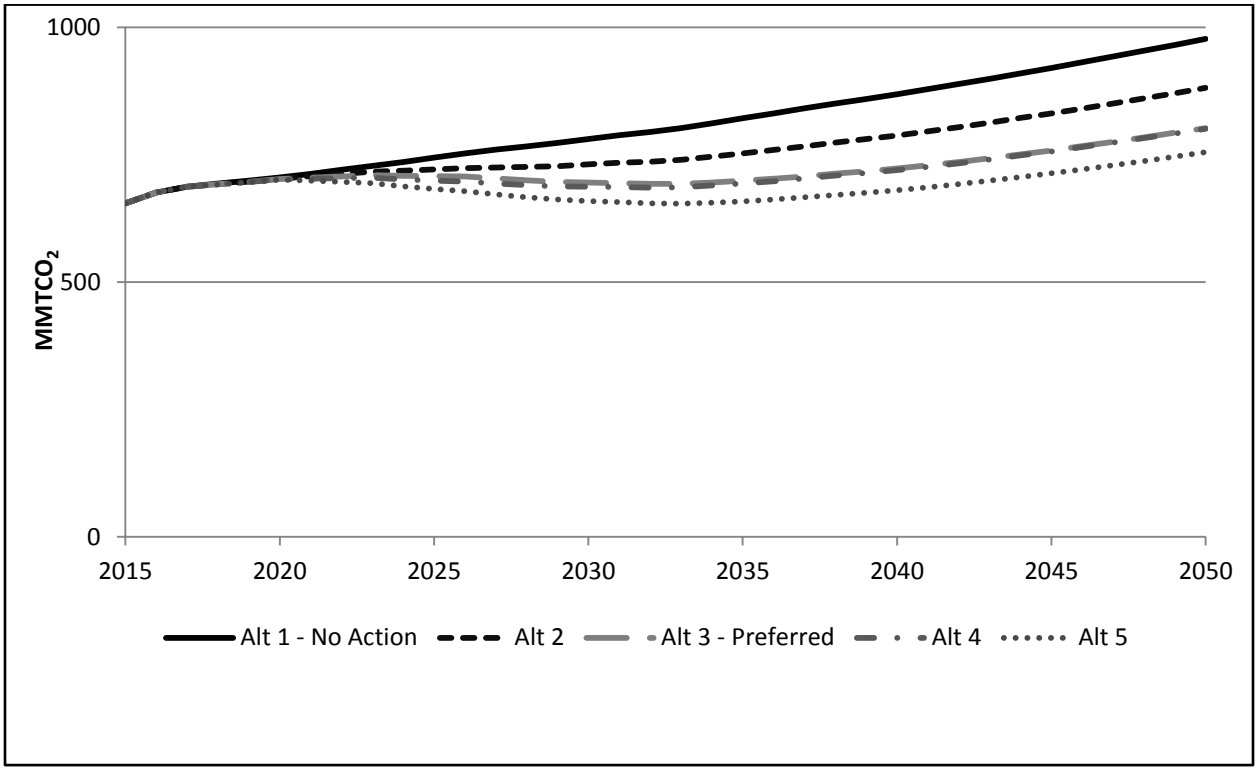


Cumulative Impacts

<u>Greenhouse Gas Emissions</u>

- Projections of total emissions reductions over the 2018–2100 period under the action alternatives and other reasonably foreseeable future actions (i.e., forecast HD vehicle fuel efficiency increases resulting from market-driven demand) compared with the No Action Alternative range from 6,500 $MMTCO_2$ (under Alternative 2) to 15,200 $MMTCO_2$ (under Alternative 5). Falling between these two extremes, the Preferred Alternative would reduce emissions by 11,800 $MMTCO_2$. The action alternatives would reduce total HD vehicle emissions by between 9 percent (under Alternative 2) and 20 percent (under Alternative 5) by 2100. Again falling between these two extremes, the Preferred Alternative would reduce total HD vehicle emissions by 16 percent by 2100. Figure S-10 shows projected annual CO_2 emissions from HD vehicles by alternative compared with the No Action Alternative.
- Compared with projected total global CO_2 emissions of 4,154,831 $MMTCO_2$ from all sources from 2018–2100, the incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.2 and 0.4 percent by 2100.

Figure S-10. Projected Annual CO_2 Emissions ($MMTCO_2$) from HD Vehicles by Alternative, Cumulative Impacts

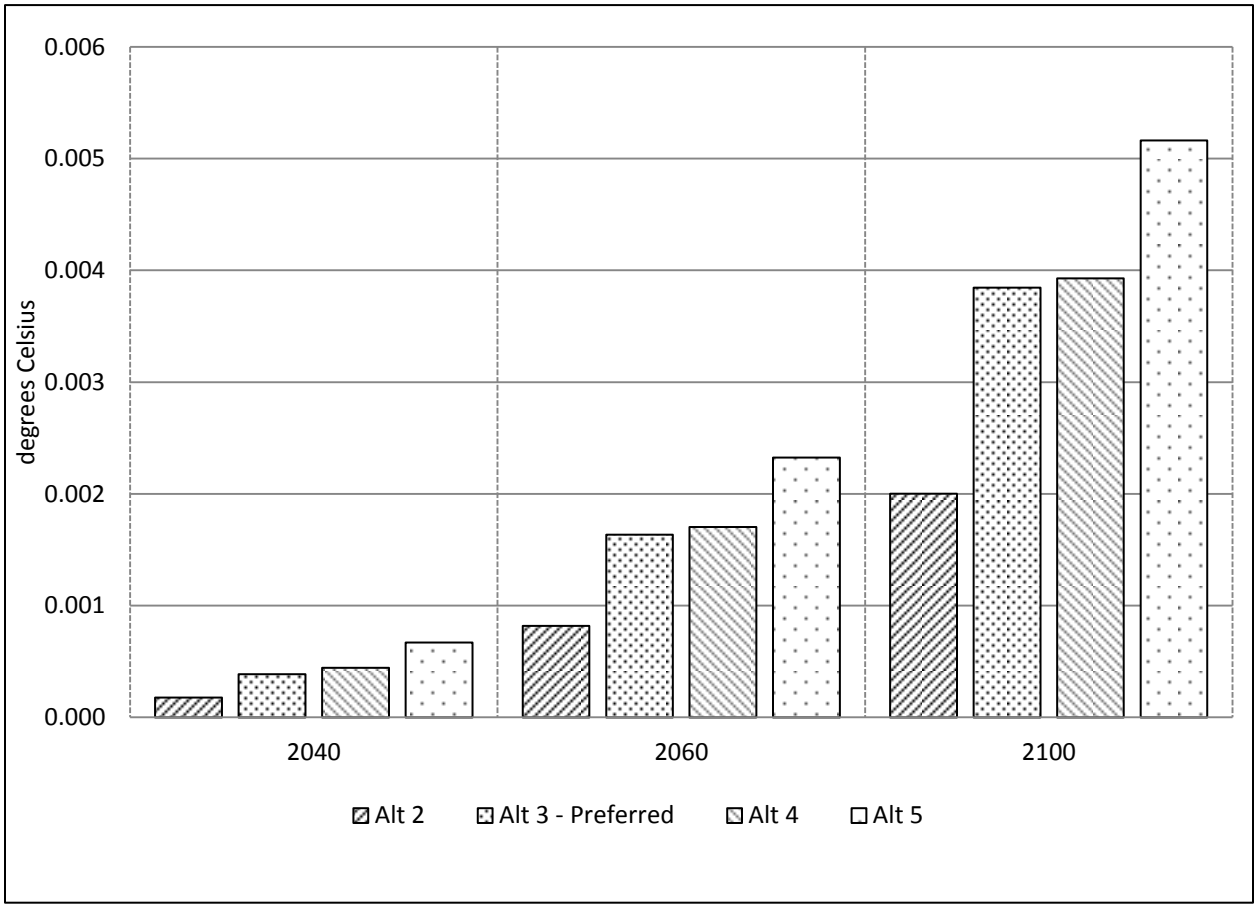


<u>CO_2 Concentration, Global Mean Surface Temperature, Sea-Level Rise, and Precipitation</u>

- Estimated atmospheric CO_2 concentrations in 2100 range from a low of 686.0 ppm under Alternative 5 to a high of 687.3 ppm under the No Action Alternative. The Preferred Alternative would result in CO_2 concentrations of 686.3 ppm, a reduction of 1.0 ppm compared with the No Action Alternative.
- The reduction in global mean temperature increase for the action alternatives compared with the No Action Alternative in 2100 ranges from a low of 0.002°C (0.004°F) under Alternative 2 to a high of 0.005°C (0.009°F) under Alternative 5. The Preferred Alternative would result in a reduction of 0.004°C (0.007°F) from the projected temperature increase of 2.838°C (5.108°F) under the No Action Alternative. Figure S-11 illustrates the reductions in the increase in global mean temperature under each action alternative compared with the No Action Alternative.
- Projected sea-level rise in 2100 ranges from a high of 70.22 centimeters (27.65 inches) under the No Action Alternative to a low of 70.12 centimeters (27.61 inches) under Alternative 5, indicating a maximum reduction of sea-level rise equal to 0.10 centimeter (0.04 inch) by 2100 from the level that could occur under the No Action Alternative. Sea-level rise under the Preferred Alternative would be 70.15 centimeters (27.62 inches), a 0.07-centimeter (0.03-inch) reduction compared with the No Action Alternative.

See Section 5.4 of this EIS for more details about direct, indirect, and cumulative impacts on climate.

Figure S-11. Reduction in Global Mean Surface Temperature Compared with the No Action Alternative, Cumulative Impacts



Health, Societal, and Environmental Impacts of Climate Change

The action alternatives would reduce the impacts of climate change that would otherwise occur under the No Action Alternative. The magnitude of the changes in climate effects that would be produced by the most stringent action alternative (Alternative 5) is roughly 1.2 ppm less CO_2, a few thousandths of a degree difference in temperature increase, a small percentage change in the rate of precipitation increase, and about 1 millimeter (0.03 inch) of sea-level rise. Although the projected reductions in CO_2 and climate effects are small compared with total projected future climate change, they are quantifiable and directionally consistent and would represent an important contribution to reducing the risks associated with climate change. Although NHTSA does quantify the reductions in monetized damages that can be attributable to each action alternative (in the social cost of carbon analysis), many specific impacts on health, society, and the environment cannot be estimated quantitatively. Therefore, NHTSA provides a detailed discussion of the impacts of climate change on various resource sectors in Section 5.5 of the EIS. Section 5.6 discusses the changes in non-climate impacts (such as ocean acidification by CO_2) associated with the alternatives.

CHAPTER 1 PURPOSE AND NEED FOR THE PROPOSED ACTION

1.1 Introduction

The Energy Policy and Conservation Act of 1975 (EPCA)[1] mandated that the National Highway Traffic Safety Administration (NHTSA) establish and implement a regulatory program for motor vehicle fuel economy.[2] As codified in Chapter 329 of Title 49 of the U.S. Code (U.S.C.), and as amended by the Energy Independence and Security Act of 2007 (EISA),[3] EPCA sets forth specific requirements concerning the establishment of average fuel economy standards for passenger cars and light trucks, which are motor vehicles with a gross vehicle weight rating (GVWR) less than 8,500 pounds and medium-duty passenger vehicles with a GVWR less than 10,000 pounds.[4] This regulatory program, known as the Corporate Average Fuel Economy Program (CAFE), was established to reduce national energy consumption by increasing the fuel economy of these automobiles.

EISA was enacted in December 2007, providing the U.S. Department of Transportation (DOT)—and NHTSA, by delegation—new authority to implement, via rulemaking and regulations, "a commercial medium- and heavy-duty on-highway vehicle[5] and work truck[6] fuel efficiency improvement program designed to achieve the maximum feasible improvement" for motor vehicles with a GVWR of 8,500 pounds or greater, except for medium-duty passenger vehicles already covered under CAFE.[7] This broad sector—ranging from large pickups to sleeper-cab tractors—represents the second-largest contributor to oil consumption and greenhouse gas (GHG) emissions from the transportation sector, after light-duty passenger cars and trucks. EISA directs NHTSA to "adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols that are appropriate, cost-effective, and technologically feasible for commercial medium- and heavy-duty on-highway vehicles and work trucks."[8] This authority permits NHTSA to set "separate standards for different classes of vehicles."[9] Commercial medium-duty and heavy-duty on-highway vehicles and work trucks, including their engines and certain trailers, are hereinafter referred to collectively as "HD

---

[1] EPCA was enacted to serve the United States' energy demands and promote energy conservation when feasibly obtainable. EPCA is codified at 49 U.S.C. § 32901 *et seq.*

[2] EPCA directs the Secretary of Transportation to set and implement fuel economy standards for passenger cars and light trucks sold in the United States. The Secretary has delegated responsibility for implementing EPCA fuel economy requirements to NHTSA. 49 CFR §§ 1.95, 501.2(a)(7).

[3] Pub. L. No. 110-140, 121 Stat. 1492 (Dec. 19, 2007). EISA amends and builds on EPCA by setting out a comprehensive energy strategy for the 21st century, including the reduction of fuel consumption from all motor vehicle sectors.

[4] 49 U.S.C. §§ 32901(a)(3), (a)(17)-(19).

[5] EISA added the following definition to the U.S.C. automobile fuel economy chapter: "commercial medium- and heavy-duty on-highway vehicle" means an on-highway vehicle with a gross vehicle weight rating of 10,000 pounds or more. 49 U.S.C. § 32901(a)(7).

[6] EISA added the following definition to the U.S.C. automobile fuel economy chapter: "work truck" means a vehicle that – (A) is rated at between 8,500 and 10,000 pounds gross vehicle weight; and (B) is not a medium-duty passenger vehicle (MDPV) (as defined in section 86.1803–01 of title 40, Code of Federal Regulations, as in effect on the date of the enactment of [EISA]). 49 U.S.C. § 32901(a)(19).

[7] 49 U.S.C. § 32902(k)(2).

[8] *Id.*

[9] *Id*.

vehicles."[10] EISA also provides for regulatory lead time and regulatory stability. EISA dictates that the HD Fuel Efficiency Improvement Program NHTSA implements must provide not fewer than 4 full model years of regulatory lead time and 3 full model years of regulatory stability.[11]

Consistent with these requirements and in consultation with the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE), NHTSA established the first fuel efficiency standards for HD vehicles in September 2011, as part of a comprehensive HD National Program to reduce GHG emissions and fuel consumption for HD vehicles.[12] Those fuel efficiency standards constituted the first phase (Phase 1) of the NHTSA HD Fuel Efficiency Improvement Program. They were established to begin in model year (MY) 2016 and remain stable through MY 2018,[13] consistent with EISA's requirements. Although EISA prevented NHTSA from enacting mandatory standards before MY 2016, NHTSA established voluntary compliance standards for MYs 2014–2015 prior to mandatory regulation in MY 2016. Throughout this EIS, NHTSA refers to the rulemaking and EIS associated with the MY 2014–2018 HD vehicle fuel efficiency standards described in this paragraph as "Phase 1" or "Phase 1 HD National Program."

In February 2014, the White House directed NHTSA and EPA to develop and issue the next phase of HD vehicle fuel efficiency and GHG standards by March 2016 (White House 2014a). Consistent with this directive, NHTSA is proposing fuel efficiency standards for HD vehicles for MYs 2018 and beyond[14] as part of a joint rulemaking with EPA to establish what is referred to as the Phase 2 HD National Program (also referred to as "Phase 2"). As with Phase 1 and as directed by EISA, NHTSA's Phase 2 HD Fuel Efficiency Improvement Program rulemaking is being conducted in consultation with EPA and DOE.[15]

---

[10] For purposes of this EIS, the term *heavy-duty* or *HD* applies to almost all on-highway engines and vehicles that are not within the range of passenger cars, light trucks, and MDPVs covered by the greenhouse gas and CAFE standards issued for model years (MY) 2017–2025. The term also does not include motorcycles. In addition, for the purpose of this EIS, this term includes recreational vehicles, which is in contrast to how this term was used in the EIS associated with the MY 2014–2018 HD vehicle fuel efficiency standards. See Section I.E.2.b of the NPRM for a discussion of why NHTSA is including recreational vehicles within the scope of the HD Fuel Efficiency Improvement Program. For background on the HD vehicle segment, and fuel efficiency improvement technologies available for those vehicles, see the following reports recently issued by the National Academy of Sciences: *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* (NAS 2010) and *Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: First Report* (NAS 2014a).

[11] 49 U.S.C. § 32902(k)(3).

[12] As explained in the HD Phase 1 September 2011 Final Rule, in the context of 49 U.S.C. § 32902(k), NHTSA interprets "fuel economy standards" as referring not specifically to miles per gallon, as in the light-duty vehicle context, but instead more broadly to account as accurately as possible for HD vehicle fuel efficiency. The Phase 1 Final Rule explained that NHTSA opted to set the fuel efficiency standards using metrics other than miles per gallon to account for the work performed by various types of HD vehicles. Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 76 FR 57106 (Sept. 15, 2011) (hereinafter "Phase 1 Final Rule").

[13] NHTSA's Phase 1 standards for HD pickups and vans allowed manufacturers to select one of two fuel consumption standard alternatives for MY 2016 and later. The first alternative defined individual gasoline vehicle and diesel vehicle fuel consumption target curves that do not change for model years 2016–2018, and are equivalent to EPA's compliance alternative of 67–67–67–100 percent target curves in MYs 2016–2017–2018–2019, respectively. The second alternative used target curves that are equivalent to the EPA's 40–60–100 percent target curves in MYs 2016–2017–2018, respectively. These standards would remain in effect indefinitely at their MY 2018 or 2019 levels until amended by a final rulemaking action. *See* Phase 1 Final Rule, *supra* note 12 at 57119.

[14] The Proposed Action would establish new standards beginning with MY 2018 for certain trailers and MY 2021 for all of the other HD vehicle categories, with stringency increases through MY 2027 for some segments. Standards would remain at the final stringency levels until amended by a future rulemaking.

[15] 49 U.S.C. § 32902(k)(2).

Pursuant to the National Environmental Policy Act[16] (NEPA), federal agencies proposing "major federal actions significantly affecting the quality of the human environment" must, "to the fullest extent possible," prepare "a detailed statement" on the environmental impacts of the proposed action, including alternatives to the proposed action.[17] To inform its development of Phase 2, NHTSA prepared this EIS, which analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives, including a Preferred Alternative, pursuant to Council on Environmental Quality (CEQ) NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations.[18]

1.2 Purpose and Need

NEPA requires that agencies develop alternatives to a proposed action based on the action's purpose and need. The purpose and need statement explains why the action is needed, describes the action's intended purpose, and serves as the basis for developing the range of alternatives to be considered in the NEPA analysis.[19] The purpose of this rulemaking is to continue to promote EPCA's goals of energy independence and security, as well as to improve environmental outcomes and national security, by continuing to implement an HD Fuel Efficiency Improvement Program that is "designed to achieve the maximum feasible improvement."[20]

Congress specified that as part of the HD Fuel Efficiency Improvement Program, NHTSA must adopt and implement appropriate test methods, measurement metrics, fuel economy standards,[21] and compliance and enforcement protocols. These required aspects of the program must be appropriate, cost effective, and technologically feasible for HD vehicles. As stated previously, Congress also directed that the standards adopted under the program must provide no fewer than 4 model years of regulatory lead time and 3 model years of regulatory stability. In developing Phase 2, NHTSA will continue to consider these EISA requirements as well as relevant environmental and safety considerations.

The 2014 White House report explained that although the standards established under the Phase 1 HD National Program have locked in long-lasting gains in fuel efficiency, HD vehicle fuel consumption is still projected to grow as more trucks are driven more miles.[22] For this reason, the White House report explained that new standards extending beyond Phase 1 are needed to further improve energy security, save money for consumers and businesses, reduce harmful air pollution, and lower costs for transporting goods. President Obama's May 29, 2014, *All-of-the-Above Energy Strategy* similarly stated that the development of Phase 2 HD fuel efficiency standards "will lead to large savings in fuel, lower CO_2 [carbon dioxide] emissions, and health benefits from reduced particulate matter and ozone."[23] To develop standards that provide long-term certainty and promote innovation, the White House directed NHTSA and EPA to work closely with both large and small stakeholders to explore further opportunities

[16] 42 U.S.C. §§ 4321–4347.

[17] 42 U.S.C. § 4332.

[18] NEPA is codified at 42 U.S.C. §§ 4321–4347. CEQ NEPA implementing regulations are codified at 40 CFR Parts 1500–1508, and NHTSA's NEPA implementing regulations are codified at 49 CFR Part 520.

[19] 40 CFR § 1502.13.

[20] 49 U.S.C. § 32902(k)(2).

[21] *See* Phase 1 Final Rule, *supra* note 12, at 57115.

[22] White House 2014, *supra* note 14, at 5.

[23] White House, New Report: The All-of-the-Above Energy Strategy as a Path to Sustainable Economic Growth (May 2014).

for fuel consumption and emissions reductions beyond MY 2018.[24] The president also directed NHTSA and EPA to consult with the California Air Resources Board (CARB) to ensure that the next phase of standards allows manufacturers to continue to build a single national fleet.[25] Additionally, the report directed NHTSA and EPA to consider the following advanced technologies, some of which may not currently be in production:

- Engine and powertrain efficiency improvements
- Aerodynamics
- Weight reduction
- Improved tire rolling resistance
- Hybridization
- Automatic engine shutdown
- Accessory improvements (e.g., water pumps, fans, auxiliary power units, air conditioning)

The Proposed Action and alternatives analyzed in this EIS have been developed to reflect the purpose and need specified by EISA, the Phase 1 HD National Program, and the 2014 White House directive.

1.3 National Environmental Policy Act and Joint Rulemaking Process

Together with this EIS, NHTSA and EPA are issuing proposed rules to establish Phase 2 fuel efficiency and GHG emissions standards for HD vehicles.[26] The proposed rules would address the urgent and closely intertwined challenges of energy independence and security and climate change by continuing strong and coordinated federal fuel efficiency and GHG emissions standards for HD vehicles through the HD National Program. The proposed rules are intended to achieve substantial reductions in fuel consumption and GHG emissions from the HD vehicle sector. The proposed rules build on the first phase of the HD National Program, established by a joint rule issued by NHTSA and EPA in September 2011, in which NHTSA set fuel efficiency standards and EPA set GHG emissions standards for MY 2014–2018 and beyond HD vehicles (Phase 1 HD National Program).[27] The proposed Phase 2 HD National Program would deliver additional environmental and energy benefits, cost savings, and administrative efficiencies nationwide using a coordinated approach.

1.3.1 Building Blocks of the National Program

The HD National Program is both needed and possible because there is a direct relationship between improving fuel efficiency and reducing carbon dioxide (CO_2) tailpipe emissions. The amount of CO_2 emissions is essentially constant per gallon combusted of a given type of fuel. The more fuel efficient a vehicle, the less fuel it burns performing a given amount of work across a given distance. The less fuel it burns, the less CO_2 it emits in performing that work across that distance. While there are emissions control technologies that reduce the pollutants (e.g., carbon monoxide) produced by imperfect combustion of fuel by capturing or destroying them, there is currently no such technology for CO_2.

[24] *Id.* at 8.

[25] *Id.*

[26] The agencies' notices of proposed rulemaking will be published in a single *Federal Register* notice as a coordinated, joint proposal.

[27] *See* Phase 1 Final Rule, *supra* note 12.

Emissions control technologies for CO_2, therefore, depend on reducing the quantity of fuel consumed. As a result, the same technologies address the twin problems of reducing fuel consumption and reducing CO_2 emissions.

1.3.1.1 DOT's HD Vehicle Fuel Efficiency Improvement Program

With the passage of EISA in December 2007, Congress provided a framework for developing the first fuel efficiency regulations for HD vehicles. In September 2011, NHTSA issued a rule establishing the Phase 1 fuel efficiency standards for HD vehicles in accordance with the EISA mandate to establish an HD "fuel efficiency improvement program designed to achieve the maximum feasible improvement."[28] In Phase 1, NHTSA set mandatory standards for HD vehicles beginning in MY 2016 and voluntary compliance standards for MY 2014–2015 HD vehicles. NHTSA set fuel efficiency standards for three categories of commercial medium- and heavy-duty on-highway vehicles and work trucks (and the engines that power them) based on the relative degree of homogeneity among trucks within each category: HD pickups and vans, vocational vehicles, and combination tractors (Phase 1 deferred action on setting standards for commercial trailers[29]). These vehicle categories are described in greater detail below in the discussion of the Proposed Action. Phase 2 builds off of Phase 1, establishing mandatory fuel efficiency standards for HD vehicles for MYs 2018 and beyond. Section 1.3.2 discusses the Proposed Action, including differences between Phase 1 and Phase 2.

1.3.1.2 EPA's Greenhouse Gas Standards for HD Vehicles

Since the 1980s, EPA has acted several times to address tailpipe emissions of criteria pollutants and air toxics from HD vehicles under its Clean Air Act (CAA) authority. Prior to the HD National Program established in September 2011, these programs have primarily addressed emissions of ozone precursors (hydrocarbons and nitrogen oxides [NO_x] and particulate matter [PM]). Under Phase 1, EPA issued GHG emissions standards for the same three classes of commercial medium- and heavy-duty on-highway vehicles and work trucks (HD pickups and vans, vocational vehicles, and combination tractors) and engines.

One difference between the EPA GHG standards and NHTSA fuel efficiency standards under the HD National Program relates to when the standards apply. As required by the CAA, EPA mobile source emissions standards apply at the time the vehicle or engine is sold, as well as when the vehicle is in actual use. This is in contrast to the NHTSA fuel consumption standards under EISA, which apply only at the time the vehicle or engine is sold.

A second difference between the EPA GHG emissions standards and the NHTSA fuel efficiency standards is that the EPA standards regulate hydrofluorocarbons (HFCs), which is a GHG of concern that may leak from vehicle air conditioning systems, but is not related to fuel efficiency. Specifically, in Phase 1, EPA established separate air conditioning refrigerant leakage standards for combination tractors and for HD pickups and vans. EPA did not adopt air conditioning refrigerant leakage standards for vocational vehicles. *See* Section II.E.5 of the Phase 1 Final Rule preamble. However, for Phase 2, EPA is proposing similar standards for vocational vehicles, beginning in MY 2021. The process for certifying that low leakage components are used would follow the system currently in place for comparable systems in tractors.

---

[28] 49 U.S.C. § 32902(k)(2); Phase 1 Final Rule, *supra* note 12.

[29] *See* Phase 1 Final Rule, *supra* note 12, at 57111 ("While we are deferring action today on setting trailer standards, the agencies are committed to moving forward to create a regulatory program for trailers that would complement the current vehicle program.").

1.3.1.3 California Air Resources Board (CARB) Greenhouse Gas Program

CARB sets motor vehicle emissions standards for the State of California. In Phase 1, NHTSA and EPA worked with a diverse group of stakeholders, including the State of California. As explained in the Phase 1 Final Rule, based on the agencies' ongoing consultation with CARB, NHTSA and EPA expected that CARB would be able to adopt regulations equivalent in practice to those of the HD National Program, just as it had done for past EPA regulation of HD trucks and engines. On December 5, 2014, California approved CARB's Phase 1 GHG regulations, which aligned California's GHG emissions standards and test procedures with the Phase 1 HD National Program (CARB 2013). In the 2014 White House report, President Obama directed NHTSA and EPA to continue to consult with CARB to ensure that the next phase of standards allows manufacturers to continue to build a single national fleet.

1.3.1.4 Light-Duty National Program

In 2010, NHTSA and EPA set fuel economy and GHG emissions standards for MY 2012–2016 passenger cars and light trucks (collectively, "light-duty vehicles").[30] In 2012, the agencies established the fuel economy and GHG emissions standards for light-duty vehicles for MYs 2017 and beyond.[31] In certain respects, the agencies used the Light-Duty National Program as a model for the HD National Program, including NHTSA's proposed Phase 2 HD fuel efficiency standards. This is most apparent in the case of medium-duty pickups and vans, which are very similar to the light-duty trucks addressed in the Light-Duty National Program both technologically and in terms of how they are manufactured (i.e., the same company often makes both the vehicle and the engine). For these vehicles, there are close parallels to the Light-Duty National Program in how the agencies have developed proposed standards and compliance structures, although for this current rule, each agency has proposed standards based on attributes other than vehicle footprint, as discussed below.

Due to the diversity of the remaining HD vehicles, there are fewer parallels with the structure of the Light-Duty National Program. The agencies, however, have maintained the same collaboration and coordination that characterized the development of the Light-Duty National Program. Most notably, manufacturers will be able to design and build to meet the requirements of a closely coordinated federal program and avoid unnecessarily duplicative testing and compliance burdens.

1.3.2 Proposed Action

NHTSA's proposed action is to set HD vehicle fuel efficiency standards, in accordance with the EISA mandate to "implement a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program."[32] As part of a joint rulemaking effort, NHTSA and EPA are proposing coordinated fuel consumption[33] and GHG emissions standards for HD vehicles to be built in MYs 2018

---

[30] Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 FR 25324 (May 7, 2010).

[31] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule, 77 FR 62624 (Oct. 15, 2012).

[32] 49 U.S.C. § 32902(k)(2).

[33] NHTSA's proposed action will be to set fuel consumption standards, as opposed to the fuel economy standards that the agency sets under the CAFE program for light-duty vehicles. Whereas fuel economy measures the distance a vehicle can travel with a gallon of fuel, and is expressed in miles per gallon (mpg), fuel consumption is the inverse metric—the amount of fuel consumed in driving a given distance. (NAS 2010). Fuel consumption is a useful measurement because it is directly related to the goal of decreasing the amount of fuel necessary for an HD vehicle to travel a given distance. Fuel consumption standards

and beyond. Reducing HD vehicle fuel consumption and GHG emissions requires increasing the inherent efficiency of the engine and reducing the work that needs to be done per mile traveled. This objective requires a focus on the entire vehicle. For example, in addition to the basic emissions and fuel consumption levels of the engine, the aerodynamics of the vehicle can have a major impact on the amount of work that must be performed to transport freight. The National Academy of Sciences (NAS) recommended this focus on both the engine and the rest of the vehicle in its reports, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-duty Vehicles* (NAS 2010) and *Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicle, Phase Two* (NAS 2014a). The proposed Phase 2 HD vehicle fuel efficiency standards that make up the HD National Program aim to address the complete vehicle, to the extent practicable and appropriate under the agencies' respective statutory authorities, through complementary engine and vehicle standards.

1.3.2.1 HD Vehicle Categories Covered by the Proposed Standards

NHTSA's HD vehicle fuel efficiency standards (including both the Phase 1 standards and the proposed Phase 2 standards as described in this EIS) apply to nearly all[34] commercial highway engines and vehicles that are not regulated by the light-duty passenger car, light-duty truck, and medium-duty passenger vehicle (MDPV) CAFE and GHG standards issued for MY 2017 and beyond. Thus, the HD Fuel Efficiency Improvement Program, unless otherwise specified, covers all vehicles rated at a GVWR greater than 8,500 pounds (except for MDPVs) and the engines that power these vehicles. EISA Section 103(a)(3) defines a "commercial medium- and heavy-duty on-highway vehicle" as an on-highway vehicle with a GVWR of 10,000 pounds or more.[35] EISA Section 103(a)(6) defines a "work truck" as a vehicle that is rated at between 8,500 and 10,000 pounds gross vehicle weight and is not an MDPV.[36] Therefore, in NHTSA's HD Fuel Efficiency Improvement Program and in this EIS, the term *HD vehicles* refers to both work trucks and commercial medium- and heavy-duty on-highway vehicles, as defined by EISA. In addition, for the purpose of this EIS, this term includes recreational vehicles, which is in contrast to how this term was used in the Phase 1 EIS. *See* Section I.E.2.b of the Notice of Proposed Rulemaking (NPRM) for a discussion of why NHTSA is including recreational vehicles within the scope of the Phase 2 Fuel Efficiency Improvement Program.

NHTSA's HD Fuel Efficiency Improvement Program (including the proposed Phase 2 standards) applies to HD engines, which are generally those installed in commercial medium- and heavy-duty trucks. This term excludes engines installed in vehicles certified to a complete vehicle emissions standard based on a chassis test, because these are addressed as a part of those complete vehicles. It also excludes engines used exclusively for stationary power when the vehicle is parked. In addition to regulating HD engines, in the Phase 1 Final Rule, NHTSA and EPA established standards for each of three different categories of HD vehicles, which together comprise the range of HD vehicles available.

---

satisfy EISA's directive that NHTSA implement a fuel efficiency improvement program because the more efficient an HD vehicle is in completing its work, the less fuel it will consume to move cargo a given distance.

[34] The agencies are proposing to exclude a small number of vehicles that would otherwise meet the definition of a commercial medium- and heavy-duty on-highway vehicle.

[35] *Codified at* 49 U.S.C. § 32901(a)(7).

[36] EISA Section 103(a)(6) is codified at 49 U.S.C. § 32901(a)(19). EPA defines medium-duty passenger vehicles as any complete vehicle between 8,500 and 10,000 pounds GVWR designed primarily for the transportation of persons that meet the criteria outlined in 40 CFR § 86.1803-01. The definition specifically excludes any vehicle that (1) has a capacity of more than 12 persons total or (2) is designed to accommodate more than 9 persons in seating rearward of the driver's seat or (3) has a cargo box (e.g., pickup box or bed) of 6 feet or more in interior length. *See* Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule, 65 FR 6698 (Feb. 10, 2000).

The proposed Phase 2 HD Fuel Efficiency Improvement Program described in this EIS follows the same general categories with a few exceptions.

- **Combination tractors (Classes 7–8):** Heavy-duty combination trucks are built to move freight. The ability of a truck to meet a customer's freight transportation requirements depends on three major characteristics of the tractor: the GVWR (which along with gross combined weight rating [GCWR] establishes the maximum carrying capacity of the tractor and trailer), cab type (sleeper cabs provide overnight accommodations for drivers), and the tractor roof height (to mate tractors to trailers for the most fuel-efficient configuration). Each of these attributes affects the baseline fuel consumption and GHG emissions, as well as the effectiveness of possible technologies like aerodynamics, and is discussed in Section III.A of the Phase 1 Final Rule. Class 7 trucks, which have a GVWR of 26,001 to 33,000 pounds and a typical GCWR of 65,000 pounds, have a lesser payload capacity[37] than Class 8 trucks. Class 8 trucks have a GVWR of greater than 33,000 pounds and a typical GCWR of 80,000 pounds. As discussed in Section IX of the Phase 1 Final Rule, the finalized fuel consumption and GHG emissions standards did not regulate trailers. However, as discussed in Section 1.3.2.2, below, NHTSA and EPA are proposing to regulate certain trailers used in combination with HD tractors as a part of the Phase 2 HD National Program.
- **HD pickups and vans (Classes 2b–3):** HD vehicles with a GVWR of 8,501 to 10,000 pounds are classified in the industry as Class 2b motor vehicles. As discussed above, Class 2b includes MDPVs that the agencies regulate under the light-duty vehicle program, and the HD National Program established in the Phase 1 Final Rule did not include additional requirements for MDPVs. HD vehicles with GVWR of 10,001 to 14,000 pounds are classified as Class 3 motor vehicles. The HD National Program regulates Classes 2b–3 HD vehicles (referred to in the EIS as HD pickups and vans) together using an approach similar to that used in the current CAFE program and the EPA GHG emissions standards for light-duty vehicles.
- **Vocational Vehicles (Classes 2b–8):** Classes 2b–8 vocational vehicles consist of a very wide variety of configurations including delivery, refuse, utility, dump, tow, and cement trucks; transit, shuttle, and school buses; emergency vehicles; and motor homes, among others. The HD National Program defines Classes 2b–8 vocational vehicles as all HD vehicles not included in HD pickups and vans or Classes 7–8 tractor segments.

Table 1.3.2-1 outlines how GVWR classes correspond to the HD vehicle categories of pickups and vans, vocational vehicles, and tractors.

Table 1.3.2-1. HD Vehicle Segments by Gross Vehicle Weight Rating (pounds)

<table>
<tr><th>Class 2b</th><th>Class 3</th><th>Class 4</th><th>Class 5</th><th>Class 6</th><th>Class 7</th><th>Class 8</th></tr>
<tr><td>8,501–10,000</td><td>10,001–14,000</td><td>14,001–16,000</td><td>16,001–19,500</td><td>19,501–26,000</td><td>26,001–33,000</td><td>>33,000</td></tr>
<tr><td colspan="2">HD pickups and vans (incl. work trucks)</td><td colspan="5"></td></tr>
<tr><td colspan="7">Vocational vehicles (e.g., van trucks, utility "bucket" trucks, tank trucks, refuse trucks, buses, fire trucks, flat-bed trucks, and dump trucks)</td></tr>
<tr><td colspan="6"></td><td>Tractors (for combination tractor-trailers)</td></tr>
</table>

[37] Payload is determined by a tractor's GVWR and GCWR relative to the weight of the tractor, trailer, fuel, driver, and equipment.

1.3.2.2 Differences between Phase 1 of the HD Fuel Efficiency Improvement Program (MYs 2014–2018) and Proposed Phase 2 (MYs 2018 and Beyond)

NHTSA is proposing new fuel efficiency standards for HD vehicles that build on and enhance existing Phase 1 standards, as well as proposing the first ever standards for certain trailers used in combination with HD tractors. Classes 7–8 tractors and their trailers account for approximately two-thirds of the HD vehicle sector's total CO_2 emissions and fuel consumption. Although trailers do not directly generate exhaust emissions or consume fuels (except for the refrigeration units on refrigerated trailers), their designs and operation nevertheless contribute substantially to the CO_2 emissions and diesel fuel consumption of the tractors pulling them. The proposed trailer standards are expressed as CO_2 and fuel consumption standards, and would apply to each trailer regarding the emissions and fuel consumption that would be expected for a specific standard type of tractor pulling such a trailer. NHTSA and EPA believe it is appropriate to establish standards for trailers separately from tractors because they are separately manufactured by distinct companies. The agencies are not proposing standards for CO_2 emissions and fuel consumption from the transport refrigeration units (TRUs) used on refrigerated box trailers. Additionally, EPA is not proposing standards for hydrofluorocarbon (HFC) emissions from TRUs. *See* Section IV of the NPRM for additional background and detail on trailer considerations and the proposed trailer standards.

Taken together, the Phase 2 program would comprise a set of technology-advancing[38] standards that would achieve greater GHG and fuel consumption savings than the Phase 1 program, predicated on use of both off-the-shelf technologies and emerging technologies that are not yet in widespread use. The agencies are proposing standards for MY 2027 that would likely require manufacturers to make extensive use of these technologies. Phase 2 will carry over many of the compliance approaches developed for Phase 1, with certain changes as described in Section I.C.1 of the NPRM preamble.

Table 1.3.2-2 summarizes the difference between the Phase 1 and proposed Phase 2 fuel efficiency standards for HD vehicles across categories. Following Table 1.3.2-2 is a narrative summary of Phase 2 proposal that points readers to sections of the NPRM that contain additional detail regarding the Proposed Action for specific regulated categories of HD vehicles.

[38] In this context, the term "technology-advancing" means standards that will effectively require manufacturers to develop new technologies (or to significantly improve technologies), as distinguished from standards that can be met using off-the-shelf technology alone. The proposed standards do not require manufacturers to use any specific technologies.

Table 1.3.2-2. Summary of Phase 1 and Proposed Phase 2 HD Vehicle Programs

	Phase 1 Program	Proposed Phase 2 Program
Engines installed in tractors and vocational chassis		
Share of HD vehicle fuel consumption and GHG emissions	Combination tractors and vocational vehicles account for approximately 85% of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Gallons of fuel/brake horsepower-hour (gal/100 bhp-hr).	
Example technology options available to help manufacturers meet standards	Combustion, air handling, friction, and emissions after-treatment technology improvements.	Increased use of Phase 1 technologies, plus waste heat recovery systems for tractor engines.
Flexibilities	ABT program that allows emissions and fuel consumption credits to be averaged, banked, or traded (5-year credit life). Manufacturers allowed to carry forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	Same as Phase 1, except no advanced technology incentives.
Tractors designed to pull trailers and move freight		
Share of HD vehicle fuel consumption and GHG emissions	Combination tractors and their engines account for approximately two-thirds of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Gallons of fuel/1,000 ton payload mile (gal/1,000 ton-miles).	
Example technology options available to help manufacturers meet standards	Aerodynamic drag improvements, low-rolling resistance tires, engine efficiency improvements, high strength steel and aluminum weight reduction, extended idle reduction, and speed limiters.	Increased use of Phase 1 technologies, plus additional engine improvements, improved and automated transmissions, powertrain optimization, tire inflation systems, and predictive cruise control.
Flexibilities	ABT program that allows emissions and fuel consumption credits to be averaged, banked, or traded (5-year credit life). Manufacturers allowed to carry forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	Same as Phase 1, except no extra credits for advanced technologies or early certification.

Trailers hauled by tractors, except those qualified as logging, mining, stationary or heavy-haul		
Share of HD vehicle fuel consumption and GHG emissions	Trailers are modeled with combination tractors and their engines. Together, they account for approximately two-thirds of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Trailers were not regulated in Phase 1.	Gallons of fuel/1,000 ton payload mile (gal/1,000 ton-miles).
Example technology options available to help manufacturers meet standards		Low-rolling resistance tires, automatic tire inflation systems, trailer weight reduction, aerodynamic improvements such as side and rear fairings, gap closing devices, and undercarriage treatment.
Flexibilities		One year delay in implementation for small businesses, trailer manufacturers may use pre-approved devices to avoid testing, averaging program for manufacturers of dry and refrigerated box trailers.
Classes 2b–8 chassis that are intended for vocational services[a]		
Share of HD vehicle fuel consumption and GHG emissions	Vocational vehicles account for approximately 20% of fuel use and GHG emissions in the medium and heavy duty truck sector categories.	
Form of the standard	Gallons of fuel/1,000 ton payload mile.	
Example technology options available to help manufacturers meet standards	Low-rolling resistance tires and engine improvements.	Further technology improvements and increased use of Phase 1 technologies, plus improved engines, transmissions and axles, powertrain optimization, weight reduction, hybrids, and workday idle reduction systems.
Flexibilities	ABT program that allows emissions and fuel consumption credits to be averaged, banked, or traded (5 year credit life). Manufacturers allowed to carry-forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	Same as Phase 1, except no advanced technology incentives. Chassis intended for emergency vehicles have proposed Phase 2 standards based only on Phase 1 technologies, and may continue to certify using a simplified Phase 1-style GEM tool.

Classes 2b–3 complete pickup trucks and vans[b]		
Share of HD vehicle fuel consumption and GHG emissions	HD pickups and vans account for approximately 15% of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Target curves based on a "work factor" attribute that combines truck payload and towing capabilities, with an added adjustment for 4-wheel drive vehicles. There are separate target curves for diesel-powered and gasoline-powered vehicles.	
Example technology options available to help manufacturers meet standards	Engine improvements, transmission improvements, aerodynamic drag improvements, low-rolling resistance tires, weight reduction, and improved accessories.	Further technology improvements and increased use of all Phase 1 technologies, plus engine stop-start, and powertrain hybridization (mild and strong).
Flexibilities	Two optional phase-in schedules; ABT program, which allows emissions and fuel consumption credits to be averaged, banked, or traded (5-year credit life). Manufacturers allowed to carry forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	ABT program proposed the same as Phase 1. Adjustment factor of 1.25 proposed for credits carried forward from Phase 1 to Phase 2 due to proposed change in useful life. Proposed cessation of advanced technology incentives in 2021 and continuation of off-cycle credits.

Notes:

[a] Vocational services include delivery vehicles, emergency vehicles, dump truck, tow trucks, cement mixer, refuse trucks, etc., except those qualified as off-highway vehicles. Because of sector diversity, vocational vehicle chassis are segmented into Light, Medium and Heavy Duty vehicle categories and for Phase 2 each of these segments are further subdivided using three duty cycles: regional, multi-purpose, and urban.

[b] Including all work vans and 15-passenger vans but excluding 12-passenger vans, which are subject to light-duty standards

GHG = greenhouse gas; ABT = averaging, banking, and trading; gal/100 bhp-hr = gallons per 100 brake horsepower-hour; GEM = Greenhouse Gas Emission Model.

HD Vehicle Engines

NHTSA and EPA are proposing to continue the basic Phase 1 structure for the Phase 2 engine standards. There would be separate standards and test cycles for tractor engines, vocational diesel engines, and vocational gasoline engines. However, the NPRM proposes a revised test cycle for tractor engines to better reflect actual in-use operation. For diesel engines, the agencies are proposing to increase the stringency of engine standards. For gasoline vocational engines, however, the agencies are not proposing more stringent engine standards. *See* Section II of the NPRM for a complete discussion of the Proposed Action as it relates to HD vehicle engines.

Classes 7–8 Combination Tractors

As explained in Section III of the NPRM, NHTSA and EPA are proposing to largely continue the Phase 1 tractor program but to propose new, more stringent standards. The agencies project that the proposed tractor standards could be met through improvements in various tractor engine and vehicle technologies. The agencies are proposing to enhance the Greenhouse Gas Emission Model (GEM) vehicle simulation tool to recognize these technologies, as described in Section II.C of the NPRM.

Classes 7–8 Trailers

The Phase 2 NPRM proposes fuel consumption and GHG emissions standards for manufacturers of new trailers that are used in combination with tractors. As described in Section IV of the NPRM, there are aerodynamic and tire technologies available to manufacturers to accomplish these proposed standards.

For the most part, these technologies have already been introduced into the market to some extent through EPA's voluntary SmartWay program. However, adoption is still somewhat limited.

NHTSA's fuel consumption standards would be voluntary beginning in MY 2018 and be mandatory beginning in MY 2021, while EPA's GHG emissions standards would be mandatory beginning in MY 2018. As described in Section XV.D and Chapter 12 of the Draft Regulatory Impact Analysis (RIA), the NPRM proposes special provisions to minimize the impacts on small trailer manufacturers.

Classes 2b–8 Vocational Vehicles

The NPRM proposes to revise the Phase 1 vocational vehicle program and to propose new standards. These proposed standards also reflect further sub-categorization from Phase 1, with separate proposed standards based on mode of operation: urban, regional, and multi-purpose. NHTSA and EPA are also proposing alternative standards for emergency vehicles. The NPRM also proposes revisions to the compliance regime for vocational vehicles. These include the addition of an idle cycle that would be weighted along with the other drive cycles; and revisions to the vehicle simulation tool to reflect specific improvements to the engine, transmission, and driveline. *See* Section V of the NPRM for a complete discussion of the Proposed Action as it relates to Classes 2b–8 vocational vehicles.

HD Pickups and Vans (Classes 2b–3)

The NPRM proposes new Phase 2 fuel consumption and GHG emissions standards for HD pickups and vans that would be applied in largely the same manner as the Phase 1 standards. These standards are based on the extensive use of most known and proven technologies. These proposed standards would commence in MY 2021. *See* Section VI of the NPRM for a complete discussion of the Proposed Action as it relates to HD pickups and vans.

1.4 Cooperating Agencies

Under 40 Code of Federal Regulations (CFR) § 1501.6, a federal agency that has special expertise with respect to any environmental issue that should be addressed in the EIS may be a cooperating agency upon request of the lead agency. On May 12, 2014, NHTSA invited EPA, DOE, and the DOT's Federal Motor Carrier Safety Administration (FMCSA) to become cooperating agencies with NHTSA in the development of this EIS for the Phase 2 HD National Program. EPA has special expertise in the areas of climate change and air quality, DOE has special expertise in vehicle technologies that improve fuel efficiency, and FMCSA has special expertise in HD vehicles. (*See* Section 1.5 of the *Medium- and Heavy-Duty Fuel Efficiency Improvement Program Final Environmental Impact Statement* (NHTSA 2011) for additional discussion of EPA's and FMCSA's expertise.)

In its invitation letters, NHTSA suggested that EPA, DOE, and FMCSA roles in the development of the EIS could include the following, as they relate to the agencies' areas of special expertise:

- Identifying the significant issues to be analyzed in the EIS from a fuel use, climate change, and air quality perspective for heavy-duty vehicles.
- Participating in the scoping process as appropriate and, in particular, assisting NHTSA to "identify and eliminate from detailed study the issues which are not significant or which have been covered by prior environmental review (§ 1506.3), narrowing the discussion of these issues in the statement

to a brief presentation of why they will not have a significant effect on the human environment or providing a reference to their coverage elsewhere."[39]

- Providing information and expertise on manufacture, sale, operation, and maintenance, of heavy-duty vehicles.
- Providing information and expertise related to technologies for improving the fuel efficiency of heavy-duty vehicles.
- Providing technical assistance, information, and expertise for modeling environmental impacts related to manufacture and use of heavy-duty vehicles.
- Participating in coordination meetings, as appropriate.
- Reviewing and commenting on the Draft EIS and Final EIS prior to publication.

EPA and DOE accepted NHTSA's invitation and agreed to become cooperating agencies. Staff members from each of these agencies participated in technical discussions, provided technical assistance, and/or reviewed and commented on this Draft EIS prior to publication.

1.5 Public Review and Comment

On July 9, 2014, NHTSA published a Notice of Intent (NOI) to prepare an EIS for Phase 2 of the HD Fuel Efficiency Improvement Program.[40] The NOI described the statutory requirements for the standards, provided initial information about the NEPA process, and initiated scoping[41] by requesting public input on the scope of the environmental analysis. Two important purposes of scoping are (1) identifying the substantial environmental issues that merit in-depth analysis in the EIS and (2) identifying and eliminating from detailed analysis the environmental issues that are not substantial and, therefore, require only brief discussion in the EIS.[42] Scoping should "deemphasize insignificant issues, narrowing the scope of the environmental impact statement process accordingly."[43] Consistent with NEPA and its implementing regulations, NHTSA made the NOI available on its website and subsequently mailed it to the following individuals and groups.

- Contacts at federal agencies with jurisdiction by law or special expertise regarding the environmental impacts involved, or authorized to develop and enforce environmental standards, including other agencies within DOT.
- The Governors of every state and U.S. territory.
- Organizations representing state and local governments.
- Native American tribes and tribal organizations.
- Individuals and contacts at other stakeholder organizations that NHTSA reasonably expects to be interested in the NEPA analysis for Phase 2 of the HD Fuel Efficiency Improvement Program, including advocacy, industry, and other organizations.

---

[39] 40 CFR § 1501.7(a)(3).

[40] Notice of Intent to Prepare an Environmental Impact Statement for New Medium- and Heavy-Duty Fuel Efficiency Improvement Program Standards, 79 FR 38842 (July 9, 2014).

[41] Scoping, as defined under NEPA, is an early and open process for determining the scope of issues to be addressed in an EIS and for identifying the significant issues related to a proposed action. *See* 40 CFR § 1501.7.

[42] *See* 40 CFR §§ 1500.4(g), 1501.7(a).

[43] 40 CFR § 1500.4(g).

1.5.1 Scoping Comments

NHTSA received responses to its NOI from 11 government agencies, 5 advocacy groups, 13 industry organizations, and 2 individuals. This section summarizes the key issues raised in these scoping comments. To view the full comment letters, visit www.regulations.gov and enter the search term "NHTSA-2014-0074," which corresponds to the docket number for this EIS. All comments will be displayed in the search results. Though NEPA does not require an agency to respond to scoping comments, NHTSA has provided responses where appropriate to address key issues raised in the comments received.

Several commenters referenced or submitted studies, research, and other information supporting or in addition to their comments. NHTSA has carefully reviewed these submissions for use in this EIS, including consideration of public availability, relevance for each resource area, and whether or not the submission was peer reviewed or included in the IPCC Fifth Assessment Report. *See* Appendix C for a list of all references and models included in the scoping comments.

1.5.1.1 Government Agencies

1.5.1.1.1 Summary of Comments Received

NHTSA received letters from ten state agencies, including the State of Alabama (NHTSA-2014-0074-0008), North Carolina Department of Administration (NHTSA-2014-0074-0010), Michigan DOT (NHTSA-2014-0074-0011), State of Nebraska (NHTSA-2014-0074-0020), Oregon DOT (NHTSA-2014-0074-0024), Maryland DOT (NHTSA-2014-0074-0005, NHTSA-2014-0074-0032, NHTSA-2014-0074-0033), Wisconsin DOT (NHTSA-2014-0074-0029), State of Arkansas (NHTSA-2014-0074-0030), State of Missouri (NHTSA-2014-0074-0031), and Commonwealth of Puerto Rico DOT (NHTSA-2014-0074-0027). NHTSA also received a letter from the U.S. Air Force requesting to be added to the distribution list (NHTSA-2014-0074-0003).

Several state agencies expressed concerns regarding the Proposed Action's potential to indirectly decrease federal funding to states for highway improvements and other projects by decreasing fuel consumption and, consequently, gas tax revenue. For example, a number of agencies maintained that reduced fuel consumption under the proposed rule would result in a decrease in revenues generated from the motor fuel taxes for the Highway Trust Fund. Because such a decrease in revenues could reduce outlays to states, thus reducing states' capabilities to properly maintain highway systems, the State of Alabama and Michigan DOT expressed concern that negative environmental impacts could result when states are unable to add sufficient capacity for future increases in congestion. For this reason, these agencies urged NHTSA to consider the impacts of the Proposed Action on highway funding, including the ability of state highway agencies to remedy congestion, negative fuel efficiency-related impacts associated with reduced highway quality, and costs related to transportation facility use, planning design, construction and maintenance.

Similarly, the North Carolina Department of Environment and Natural Resources expressed concern that the Proposed Action's reductions in fuel consumption would decrease the fee-based income received by the Leaking Underground Storage Tank program derived from sales tax on fuel and tank operating feeds, which may result in a reduction of funding available to remediate soil and groundwater contamination. This commenter also stated, however, that these impacts could be offset by tax rate and operating fee adjustments as needed.

The Maryland DOT commented that the rulemaking does not have any unacceptable impacts on its current plans or programs. The States of Arkansas and Missouri similarly reported that their states did

not have any comments to offer at this time. In contrast, the State of Alabama raised a number of concerns regarding the Phase 2 HD National Program rule. Expressing concern for potential conflicts with existing regulation, this commenter urged NHTSA to reduce or eliminate conflicting regulation, as appropriate. The State of Alabama highlighted rolling resistance technology as an area of particular concern, commenting that while reducing friction can increase fuel efficiency, it can also contribute to highway crashes if not properly accounted for. The State urged NHTSA and EPA to fully investigate claims of all technologies, stating that some fuel-saving technologies' long-term costs outweigh initial benefits and that some are not as effective as marketed. Additionally, the State of Alabama requested that NHTSA question the reliability of the science supporting the alleged need to reduce GHG emissions. It further encouraged NHTSA and EPA to use the best available modeling to analyze other potential harms and benefits to the environment in addition to climate change. The State of Alabama also expressed concerns with practicability and enforceability based on the variability of HD vehicles addressed by the Proposed Action, urging NHTSA to fully consider how requirements would be measured on each of the many HD vehicles subject to the Phase 2 standards, taking into account the location, type, and frequency of their uses.

Commenting that the truck manufacturing industry is important to Michigan's economy, the Michigan DOT expressed concern that imposing a significant cost burden on truck manufacturers has the potential to undermine their economic success. Urging NHTSA to interpret EISA's "not less than four model years of lead time" as a minimum, this commenter suggested phasing options based on type of HD vehicle for implementation of the Phase 2 standards. The Michigan DOT also urged NHTSA to review the Phase 1 HD standards prior to issuing Phase 2 standards and to consider possible grant or loan programs to help truck manufacturers and owners meet new standards. The Wisconsin DOT similarly expressed concern regarding the economic impacts of the proposal, especially from the manufacturer perspective, urging that NHTSA identify the economic hardship smaller manufacturers might face in meeting Phase 2 standards. This commenter stated that NHTSA did not address mitigation for any negative impacts of the Proposed Action.

The Wisconsin DOT further suggested that potential increases in vehicle miles traveled (VMT) and the resultant environmental and social impacts should be considered in the EIS. The Michigan DOT commented that NHTSA should consider the potential for the proposed rule to increase alternative fuel component disposal impacts on the environment. Expressing concern that increased fuel economy standards may not reduce air toxics near highways, the Michigan DOT referred NHTSA to the Federal Highway Administration's and EPA's "National Near Road Study – Detroit."

The State of Nebraska's comments focused on the potential unintended consequences of the Proposed Action as they would impact its highway-agency-operated fleet of HD maintenance trucks. Specifically, the State commented that (1) if HD vehicles have decreased power or functionality, become more expensive, have delayed production availability, or are offered by fewer vendors, the state highway agency's seasonal operations may be impaired or made less efficient, which could increase fuel consumption and emissions, and (2) compliance through the emissions credit system may permit engines that are compliant on paper, but do not benefit Nebraska's environment.

The Oregon DOT discussed the benefits of NHTSA's Proposed Action. It maintained that decreased fuel consumption would reduce fossil fuel dependence and therefore improve national security. Correspondingly, this state agency urged NHTSA's NEPA analysis to consider that decreased emissions would result in less pollution-related illnesses and decrease public health costs, including avoided mortality. In regard to assessing climate impacts, the Oregon DOT advised using the most up-to-date social cost of carbon estimates and including black carbon as an air pollutant. This commenter further requested that the EIS analyze the life cycle costs associated with new vehicle manufacturing and HD

vehicle operational benefits and costs under the proposed Phase 2 standards, including return on investment analyses.

The Commonwealth of Puerto Rico DOT also demonstrated support for the rulemaking, stating that improved fuel efficiency will help to control GHGs and mitigate climate change. This commenter urged NHTSA to choose the upper bound of maximum feasible improvement as the Preferred Alternative.

1.5.1.1.2 NHTSA Response

NHTSA has reviewed the comments provided by the government agencies, especially by the states.

First, in this EIS, NHTSA does not address the proposed rule's potential impacts on the Highway Trust Fund or environmental impacts that could result from reductions in highway funding. Predictions about Highway Trust Fund impacts and subsequent environmental effects are not only highly speculative, but also impossible to quantify or assess. In addition, NHTSA does not consider financial impacts on the Highway Trust Fund to be the kinds of impacts on the quality of the "human environment" that require analysis in an EIS. According to CEQ regulations, "human environment" includes "the natural and physical environment and the relationship of people with that environment." 40 CFR § 1508.14. Economic and social impacts are only relevant for analysis when they are interrelated with natural or physical impacts. *Id.* Here, however, the analysis requested is entirely economic in nature and not caused by changes to the natural or physical environment. As a result, it is not relevant for further study as an environmental impact under NEPA.

Second, in response to the issues raised by several other states, NHTSA has considered the various HD fuel efficiency technologies holistically, and always with an eye toward safety. NHTSA addresses vehicle safety in Section 7.4 of the EIS and Chapter 9 of the NPRM. We have conducted independent analyses of the effectiveness of the various technologies as documented in the NPRM. NHTSA has tailored its proposal to account for the wide array of HD vehicles and achieve what it believes is the maximum feasible improvement, accounting for technological feasibility, appropriateness, and cost effectiveness. The technologies that are expected to be implemented to comply with the proposed standards are not anticipated to reduce consumer choice, detrimentally impact vehicle effectiveness, or create significant cost burdens. *See* the NPRM for more information. NHTSA addresses air quality emissions (including near roadway impacts) in Chapter 4 of this EIS. NHTSA also addresses climate change impacts in Chapter 5 of this EIS. The science of climate change and the need for GHG emissions reductions to mitigate the harmful impacts of climate change have been extensively analyzed and documented by EPA and the scientific community, and those findings are discussed in Chapter 5 as well.

1.5.1.2 Advocacy Groups

1.5.1.2.1 Summary of Comments Received

NHTSA received letters from five advocacy groups, including the Center for Biological Diversity (CBD) (NHTSA-2014-0074-0009), the Environmental Defense Fund (EDF) (NHTSA-2014-0074-0013), a joint letter from the EDF, the Union of Concerned Scientists, Natural Resources Defense Council, and the Institute for Policy Integration (referred altogether as EDF et al.) (NHTSA-2014-0074-0021), the American Council for an Energy-Efficient Economy (ACEEE) (NHTSA-2014-0074-0018), and Consumer Federation of America (CFA) (NHTSA-2014-0074-0012).

Many of the comments submitted by CBD and EDF touched on similar themes. Both groups recommended developing alternatives based on the full suite of available technologies and suggested NHTSA not exclude alternatives based on owner and operator costs. Along these lines, CBD suggested

including future technologies that are currently in the research phase that could be developed within the rulemaking period. Both CBD and EDF requested that the alternatives require fuel-efficient and cost-effective technologies that are truly technology advancing, including bottom cycling, aerodynamics, tire improvements, hybrid powertrains, and idle reduction. These commenters recommended that NHTSA implement only the most stringent alternative. Additionally, they suggested that NHTSA consider reductions greater than 40 percent compared to 2010 levels, which is the amount of reductions that the Phase 1 and Phase 2 National Program standards could cost-effectively achieve by 2025, as estimated in a joint study by EDF, Union of Concerned Scientists, the Sierra Club, Natural Resources Defense Council, and ACEEE. Both CBD and EDF also discussed the science of climate change, agreeing that NHTSA should rely on the Intergovernmental Panel on Climate Change's Fifth Assessment Report to inform its analysis. Both organizations requested that NHTSA use the most up-to-date social cost of carbon estimates and provided current data and references on these estimates. EDF et al. submitted to the EIS docket those organizations' social cost of carbon comments on the Office of Management and Budget's Technical Support Document, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order No. 12866."

CBD provided additional comments regarding the alternatives analysis. It requested that the EIS present the consequences of the alternatives in a way that does not artificially minimize the true impact the more stringent alternatives can have by misleadingly depicting their impacts as negligible. On this point, CBD suggested that NHTSA analyze and disclose the comparative effects of its range of alternatives and depict the reasonably foreseeable outcome of the selected alternatives. Specifically, this commenter recommended comparing the alternatives' emissions reductions to all on-road U.S. carbon emissions, all U.S. transportation-related carbon emissions, all U.S. emissions, and all global emissions. CBD recommended that NHTSA determine the GHG emissions reduction that would allow the HD vehicle sector to stay within its proportionate share of the remaining carbon budget of approximately 1,000 gigatons of CO_2. CBD also urged NHTSA to analyze the extent to which each of the proposed alternatives would contribute proportionally to staying within the carbon budget, and the extent to which each would accomplish a reduction of U.S. GHG emissions to 17 percent below 2005 levels by 2020, to 25 to 40 percent below 1990 levels by 2020, and to 80 percent below 1990 levels by 2050. It also recommended including an alternative that accounts for and avoids or minimizes the likelihood of reaching additional climate change tipping points.

For the cumulative impacts analysis, CBD suggested that NHTSA include a scenario that assumes that other emissions source categories will do their proportional part in what is required to remain within the carbon budget. Lastly, CBD disagreed with NHTSA's proposal to analyze impacts on fuel/energy use and pollutant emissions through 2050 only, instead of through 2060 as it has done before, asserting that the basis for this determination is unsound. In general, CBD discussed how NHTSA has undercounted the benefits from increased fuel efficiency and overestimated the costs in previous EISs. In particular, this commenter urged NHTSA to properly account for all the damages caused by climate change, including recognition that mitigation costs will sharply increase over time.

In terms of EIS timing, CBD stated that, because EISA requires 4 model years of lead time, NHTSA's plan to finalize the Phase 2 standards in March 2016 appears to preclude the new standards from affecting HD vehicles before MY 2021. For this reason, CBD requested that the final rule be issued in 2015 so that it can be implemented for MY 2020 HD vehicles.

Relating to methane emissions, CBD requested that the EIS include a discussion of methane leakage based not only on the updated 100-year global warming potential of 36, but also on the 20-year global warming potential of 87. It also suggested that there is compelling evidence that leakage rates from natural gas operations are far higher than EPA emissions factors suggest. Similarly, EDF stated that

methane emissions reductions should be accounted for in the EIS and they should be evaluated at both the 100- and 20-year global warming potential time frames. This commenter noted that it finds methane emissions from natural gas vehicles especially concerning. For this reason, EDF recommended that the Phase 2 standards account for all vehicle-based methane emissions by adopting both strong tailpipe and fugitive methane standards in order to ensure that the rule does not provide incentives for the adoption of natural gas trucks. CBD specifically expressed support for NHTSA's decision to conduct full life-cycle and upstream analyses of the environmental impacts of all, and not just some, vehicle materials and technologies.

EDF also provided additional comments regarding the structure of the proposed rule and its impacts. In particular, it requested that all alternatives include separate performance-based standards for the engine, vehicle, and trailer, and urged fuel-neutral standards for each HD vehicle segment. This commenter further suggested aerodynamic and tire improvements and submitted a list of reports and studies that NHTSA should consider in the EIS. EDF also discussed the positive economic benefits of the Proposed Action, including increased employment, lowered burden on households due to decreased spending on gas, and American competitiveness in global green economies. Finally, EDF asked NHTSA to evaluate the rule's impact on fuel choice and to assess the environmental impact of changes in fuel switches through a life cycle accounting of the climate impacts associated with diesel, gasoline, natural gas, and other fuels.

ACEEE expressed support for engine and trailer standards and provided comments on baseline vehicle fleet technology assumptions, requesting that NHTSA include the National Research Council Phase 1 report technologies and technologies in the DOE SuperTruck program. This commenter also urged NHTSA and EPA to further segment the vocational vehicle category based on duty cycle and to adopt appropriate test cycles for certification. In terms of baselines, ACEEE agreed with the continuation of the 2017 baseline for the Phase 2 standards. Regarding test cycles, ACEEE commented that vehicle cycles should include road grade to better capture real-world operation. This commenter further suggested that the Preferred Alternative should reflect savings at least as high as those shown in its analysis: 34 percent reduction in fuel consumption by tractor-trailers from Phase 1 levels by 2025, 25 percent for vocational vehicles, and 17 percent for HD pickups and vans. In general, ACEEE discussed the benefits of GHG emissions reductions to national security and cost savings. Finally, ACEEE urged NHTSA to refer to California's tractor-trailer GHG rule to incorporate trailers into the Phase 2 standards and commented that CARB's extensive knowledge of issues associated with electrification of vehicle powertrains should inform the Phase 2 rule.

CFA discussed the cost savings derived from implementing the Proposed Action. It calculated that consumers would save up to $250 per year from the proposed Phase 2 standards and suggested that without the Phase 2 standards, burden on household budgets would continue to grow, reflecting increasing freight haulage and diesel fuel prices. Urging NHTSA to recognize consumers as major stakeholders in this proceeding, CFA commented that, in calculating costs and benefits, NHTSA should recognize the consumer pocketbook savings and the positive multiplier that increasing consumer disposable income has on the economy.

1.5.1.2.2 NHTSA Response

NHTSA's EIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives, as well as a No Action Alternative, designed to achieve the maximum feasible improvement in HD vehicle fuel efficiency. Technological feasibility, cost effectiveness, and appropriateness are all factors that were considered by the agency in developing this range of alternatives. The EIS presents the environmental impacts of these alternatives in comparative form,

based on the most up-to-date scientific information available. Where appropriate, the impacts are presented in a larger context, including in relation to proposed GHG emissions reductions targets (*see* Chapter 5).

Because of the models NHTSA used for this rulemaking and EIS, the agency analyzed impacts on fuel/energy use and pollutant emissions through 2050 and impacts on GHG emissions, global temperature, and climate change through 2100. Because HD vehicles generally accumulate the vast majority of their VMT in early years, and because more distant projections contain far more uncertainty, NHTSA believes the analysis year of 2050 for fuel/energy use and air quality will provide sufficient information for the decisionmaker to assess the totality of the impacts related to the regulated vehicles. Because climate impacts are more long-term, the EIS will assess these impacts to 2100. Limitations inherent in the models and projections used by the agency precluded impacts analysis beyond 2050 for fuel/energy use and air quality.

NHTSA declines to provide the "proportionate share" analysis that CBD recommends. While NHTSA appreciates the importance of reducing energy use in this sector and other sectors, it is impossible at this time to determine whether it is feasible for every economic sector to reduce energy use proportionately to achieve the stated emissions goals. Further, in the event some economic sectors cannot achieve such a reduction, it is not clear how reductions would need to be balanced across the remaining sectors to achieve these goals. Such an analysis would be too large an undertaking for purposes of this EIS, as it would require evaluating the feasibility of proportional emissions reductions across the entire economy, and would not provide relevant information for the decisionmaker.

NHTSA addresses lifecycle impacts of the technologies under consideration, including potential methane emissions, in Chapter 6 of this EIS. The structure of the program, the technologies considered, and impacts other than those on the human environment (including economic impacts) are discussed in the NPRM and Draft RIA.

1.5.1.3 Industry Organizations

1.5.1.3.1 Summary of Comments Received

NHTSA received letters from 12 industry organizations, including Prime Transport Solutions (NHTSA-2014-0074-0028), Oshkosh Corporation (Oshkosh) (NHTSA-2014-0074-0006), American Road & Transportation Builders Association (NHTSA-2014-0074-0007), the Association for the Work Truck Industry (NTEA) (NHTSA-2014-0074-0014), International Union, United Automobile, Aerospace & Agricultural Implement Workers of America (UAW) (NHTSA-2014-0074-0015), Daimler Trucks North America (Daimler) (NHTSA-2014-0074-0017), Great Dane (NHTSA-2014-0074-0019), Owner-Operator Independent Drivers Association (OOIDA) (NHTSA-2014-0074-0022), Cummins (NHTSA-2014-0074-0023), The Volvo Group (Volvo) (NHTSA-2014-0074-0025), American Trucking Associations (ATA) (NHTSA-2014-0074-0026), and Edison Electric Institute (EEI) (NHTSA-2014-0074-0016).

Most industry organizations supported a unified, national rule that reduced regulatory redundancies. For example, Cummins, ATA, and Daimler requested that EPA, CARB, and NHTSA work together closely to establish a single national program to avoid redundancies and establish goals in cooperation. Specifically, ATA expressed concern regarding CARB's proposed optional "ultra-low" NOx standards, which it purported would result in worse fuel efficiency and increased GHG emissions. Industry commenters generally supported engagement of all stakeholders in developing and evaluating the proposed Phase 2 standards. Specifically, Daimler suggested that NHTSA reach out to truck drivers and engine manufacturers in order to inform the proposed rule and EIS. OOIDA requested that NHTSA engage vehicle manufacturers, engineers, and truck drivers. In terms of cumulative impacts

methodology, this commenter recommended assessing cumulative impacts from the foreseeable future actions of other agencies such as the FMCSA rulemaking on training standards and the Research and Innovative Technology Administration's[44] study on eco-driving, implying that inclusion of training on efficiently driving a truck could contribute to additional fuel savings. Similarly, Daimler urged NHTSA to consider the impacts other regulatory actions—even those outside of NHTSA's authority—could have on CO_2 reductions, for example, increased trailer length or allowance of multiple trailers per truck.

Many industry organizations commented on the various advanced vehicle technologies to be analyzed for inclusion under the proposed rule. Commenters recommended using technologies such as aerodynamic packages, advanced transmissions, hybrids, smaller engines, lightweight materials, and engine improvements (e.g., higher compression ratios, injection pressures, and waste heat recovery). Daimler, OOIDA, and ATA expressed concern over uniform technology adoption requirements and advised against including technologies that have not been thoroughly tested and proven effective. Daimler further cautioned that NHTSA cannot mandate a fuel efficiency improvement premised on a technology while at the same time administering safety regulations that limit manufacturers' ability to implement the technology. Great Dane and Oshkosh discussed issues with specific technologies that may make them impractical for certain fleets, including low-rolling resistance tires, trailer weight reduction, aerodynamic enhancements, and engine idle reduction technologies. Prime Transport Solutions suggested including aerodynamics due to a crankless trailer leg, idle reduction time, and the safety impacts of a better crank gear. Cummins recommended that the proposed rule include a number of sub-systems of commercial vehicles, such as transmissions, which provide manufacturers with additional ways to improve fuel efficiency.

Industry organizations also commented on the structure of the HD vehicle standards. In general, commenters agreed with and appreciated NHTSA's recognition of the complexities of truck manufacturing; however, commenters overall disagreed on exactly how the Phase 2 standards should account for those complexities. Some commenters, such as NTEA, agreed with using the Phase 1 approach for vehicle classes and suggested continuing to focus on the drive train for Phase 2. Other commenters, such as Daimler, Volvo, and OOIDA, suggested that NHTSA consider a complete vehicle standard with no separate engine standard. Specifically, Daimler commented that the separate engine standard results in a difference in certified CO_2 values and real-world fuel economy improvements. Similarly, Volvo suggested performing a cost-benefit analysis of the separate engine standard, noting its overwhelming costs. Cummins suggested the addition of a powertrain testing option to the Phase 2 regulation that tests the engine and the transmission together to capture the efficiency benefits of integrated engine and active transmission systems.

Stating that the Phase 1 HD National Program adopted different and less stringent standards for gasoline engines and vehicles compared with diesel, Daimler, OOIDA, and Cummins urged NHTSA to adopt "fuel neutral" Phase 2 standards. Cummins commented that if the Phase 2 standards continue or increase the disparity between diesel and gasoline standards, the cumulatively higher costs would drive customers away from diesel and toward gasoline, which would increase CO_2 emissions across the HD vehicle fleet. Daimler and Cummins addressed the slope and workfactor of regulations for Classes 2b–3. Daimler suggested that Phase 2 use a constant slope in the workfactor equation and not include any further downsizing of engines for Classes 2b–3 vehicles. Cummins commented that the 2014 target CO_2 for a gasoline vehicle with a 5,000-pound work factor is approximately 1 percent higher than the diesel vehicle with the same work factor, but in 2018 that difference grows to almost 6 percent. Cummins

[44] In January 2014, DOT's Research and Innovative Technology Administration (RITA) became the Office of the Assistant Secretary for Research and Technology (OST-R).

further recommended developing technologies for diesel Classes 2b–3 vehicles similar to those used for light-duty gasoline vehicles.

Regarding baselines and alternatives, Cummins and Daimler recommended using Phase 1 as the foundation for the Phase 2 Preferred Alternative and to further consider technology advancement, enforcement, criteria, fairness, clarity, and market efficiency. In particular, Cummins suggested that separate engine and vehicle standards should be the basis for all regulatory alternatives. Daimler specifically advised selecting a Preferred Alternative that does not create market disruptions. It requested transparency when choosing the baseline for vehicle standards and advised against using the GHG Emissions Model 2017 vehicle as a baseline because there are several updates that need to be made since Phase 1. In terms of potential new alternatives, Volvo suggested that NHTSA consider maintaining the current Phase 1 standards without change for vocational HD vehicles because of the diversity of application duty cycles in that vehicle category. Volvo further commented that, in addition to vehicle regulations, improvements to transportation infrastructure and market incentives to enhance shipping efficiency should be part of any effort to reduce GHG emissions.

Regarding timing of the Phase 2 standards, Daimler commented that because the Phase 1 standards mandate an additional round of stringency that takes effect in 2017, Phase 2 standards that go into effect in 2019 would not provide the EISA-required 3 model years of regulatory stability and suggested that Phase 2 standards should not regulate before 2025. This commenter further stated that tying the effective date of the regulation to a model year creates an artificial constraint on the HD vehicle industry where model years are not tightly linked to vehicle build year and vehicle model years are not linked to engine model years. Consequently, Daimler suggested that new standards should take effect on a particular day, thereby regulating 1 model year of vehicle and the prior model year of engine.

Industry organizations also provided specific comments on the different categories of HD vehicles. Referring to Class 8 “over-the-road trucks,” OOIDA commented that vehicles are built to purchase specifications for a large variety of purposes. This commenter suggested that NHTSA perform its analysis from the perspective of the owners and operators of Class 8 vehicles and the different potential uses and component choices they face.

Regarding vocational vehicles, Oshkosh suggested conducting cost-benefit evaluations from the perspective of the owners and operators of vocational vehicles and the different potential uses and component choices possible for each vehicle. This commenter advocated regulating the engine rather than the vehicle and provided various rationales justifying such an approach. Daimler cautioned that further segmentation of the vocational HD vehicle category must consider the unintended consequences that could result in preventing commercial needs from being met. Cummins suggested that NHTSA focus on technologies that will provide a consistent benefit for all applications instead of technologies that will provide benefits that vary significantly by application and duty cycle. Volvo commented that, given the diversity of vocational vehicles, the negative consequences of optimizing the vehicle to more far-reaching regulatory requirements may outweigh any real world benefits and, consequently, maintaining the current Phase 1 vehicle regulation without changes may be the optimum approach for the vocational sector.

Regarding trailers, Daimler cited a study that it asserted supports EPA’s determination that tractors rarely travel without a trailer. If trailers are included in the Phase 2 standards, Great Dane suggested limiting the scope of such requirements to 53-inch or longer box trailers, accounting for tractor-trailer ratios in determining costs and benefits, and maintaining current tractor-trailer interchangeability. In general, Great Dane cautioned NHTSA to consider the varying payloads, configurations, and specifications of trailers when imposing regulations. This commenter specifically noted the large

potential impact the regulations may have on its customers' choices. ATA expressed concern about the potential conflicting impacts of a pending petition on side and front override guards, which, if granted, would significantly increase trailer weight.

Regarding NHTSA's analysis of environmental impacts, OOIDA commented that if Phase 2 standards result in HD vehicle operators having to purchase new equipment ahead of its standard replacement schedule, NHTSA must consider the environmental impact of such increased production. OOIDA further stated that NHTSA must consider indirect environmental impacts of technologies that are currently not common in the marketplace, citing impacts of frequent failure of engines designed to meet emissions requirements, such as need to tow a tractor-trailer and the chemicals that may be necessary for repair. EEI recommended that NHTSA look at upstream emissions (GHG and criteria) from the generation of all fuels if the EIS analyzes upstream emissions related to electricity generation. If the EIS includes such an analysis, EEI suggested that NHTSA account for regional variation in the current electricity baseload, as well as recently proposed GHG emissions standards for both existing and new electricity generation units. It also noted the positive impact of electric and plug-in electric vehicle (EV) technologies on the reduction of emissions, including reduced dependence on imported petroleum. EEI recommended robust assumptions concerning the likelihood of recycling EV batteries. This commenter further suggested conducting a life-cycle analysis and upstream analysis of all vehicle materials and technologies. Cummins recommended that the Phase 2 HD National Program align criteria and GHG emissions standards in order to avoid any unintended increases in criteria or GHG emissions due to differing test methods.

Industry organizations provided specific comments regarding different fuels and their consideration and analysis in the proposed rule. NTEA recommended that NHTSA analyze the opportunities to monetize credits for the implementation of alternative fuels, advanced, and innovative technologies in the vocational vehicle category. Volvo urged NHTSA to account for the potential consequences of increased methane emissions and the need for appropriate controls to ensure expected benefits from natural gas vehicles are achieved.

In terms of economic impacts of the proposed rule, UAW highlighted concern over potential negative impacts, requesting that, at a minimum, the standards be developed in a way that would not negatively impact its members. Several other commenters, including Daimler, Great Dane, OOIDA, Volvo, and ATA, also highlighted concerns over potential negative economic impacts that these commenters asserted would hit consumers the hardest. Expressing concerns regarding increased costs, some of these commenters emphasized the importance of NHTSA accurately analyzing, characterizing, and projecting the costs and benefits of the proposed Phase 2 standards. ATA and Volvo further argued that the Phase 2 standards could delay environmental objectives if new tractor, engine, and trailer costs escalate concurrently, because capital limited fleets would either pre-buy equipment in advance of the Phase 2 implementation date, hold on to existing equipment longer, lease equipment instead of buying, purchase from used equipment markets, or leave the industry. For this reason, ATA expressed support for an 18-month or shorter return on investment for all technologies considered under Phase 2.

In terms of safety impacts of the proposed rule, OOIDA stated that it is concerned about implementing technologies for GHG reductions and then discovering later that these technologies can no longer be used due to safety concerns. To illustrate this point, OOIDA cited the optional use of automatic engine shutdown switches under the Phase 1 standards. Volvo emphasized that the resolution of potential negative impacts on vehicle safety and GHG emissions is necessary before any technology can be considered ready for deployment, stating that impacts of potential technologies on braking, vehicle stability, visibility, and other safety concerns must be considered.

Several industry organizations expressed concerns regarding potential unintended impacts from the Proposed Action. The unintended impacts addressed by these commenters include unproven technologies and potential engine failures, impacts on the trucking industry from trucks having less power to haul goods, manufacturers leaving the industry, and increased maintenance costs. The American Road & Transportation Builders Association suggested that the EIS should acknowledge and attempt to mitigate the adverse effects of the Phase 2 standards on funding available for states to maintain transportation infrastructure through the Highway Trust Fund, which it asserted include effects from reduced congestion relief and impacts on employment due to delay or cancellation of transportation improvements.

1.5.1.3.2 NHTSA Response

NHTSA appreciates the wide variety of comments received by the various industry organizations. NHTSA and EPA have engaged in extensive stakeholder outreach, as described in the NPRM, to inform the development of the proposed rule. The NPRM and Draft RIA document the various studies undertaken to analyze the technologies that may be implemented for the different regulatory segments, and describe how the agencies accounted for numerous factors in the development of the proposal, including the diversity of HD vehicles, impacts of technology on vehicle safety, the effectiveness of the various technologies, implementation costs, and more. The agencies were also informed by the comments submitted by these organizations. The NPRM and Draft RIA analyze the economic impacts associated with the proposed rule, while this EIS analyzes the environmental impacts of the proposal, including potential upstream and lifecycle emissions.

1.5.1.4 Individuals

1.5.1.4.1 Summary of Comments Received

NHTSA received letters from Gary Dewyn (NHTSA-2014-0074-0002) and Christopher Lish (NHTSA-2014-0074-0004). Gary Dewyn demonstrated an overall concern with NHTSA's assumptions for clean technologies. He stated that although Phase 1 standards have resulted in cleaner engines, they have also resulted in a number of combined failures that have not only added tens of thousands of dollars in maintenance costs over the service life of a truck tractor but have also added downtime of several days per incident. This commenter asserted that such additional costs get passed on to consumers.

Christopher Lish urged NHTSA to implement a regulation that provides the maximum feasible fuel-efficiency improvement. His comment notes the benefits of fuel efficiency to the economy (especially consumers), national security, the environment, and human health.

1.5.1.4.2 NHTSA Response

NHTSA believes its proposal accurately accounts for the maintenance costs associated with the technologies expected to be implemented by manufacturers to comply with the proposed standards. For more information regarding this issue, please see the NPRM and Draft RIA.

1.6 Next Steps in the National Environmental Policy Act and Joint Rulemaking Process

This Draft EIS is being issued for public review and comment concurrently with the notice of proposed rulemaking (NPRM) to establish fuel efficiency and GHG emissions standards for MYs 2018 and beyond HD vehicles issued jointly by NHTSA and EPA. Individuals may submit their written comments on the Draft EIS, identified by docket number NHTSA-2014-0074, by any of the following methods.

- **Federal eRulemaking Portal:** Go to http://www.regulations.gov. Follow the instructions for submitting comments on the electronic docket site by clicking on "Help" or "FAQ." The Docket Number for this EIS is "NHTSA-2014-0074."
- **Mail:** Mail written comments to Docket Management Facility, M-30, U.S. Department of Transportation, 1200 New Jersey Avenue SE, West Building, Ground Floor, Room W12-140, Washington, D.C. 20590.
- **Hand Delivery:** Deliver comments in person to 1200 New Jersey Avenue SE, West Building Ground Floor, Room W12-140, between 9:00 a.m. and 5:00 p.m. eastern time, Monday through Friday, except federal holidays.
- **Fax:** Fax comments to (202) 493-2251.

Comments on this Draft EIS must be received by no later than August 31, 2015. NHTSA expects to release the Final EIS, which will address comments received on the Draft EIS, in early 2016. NHTSA will simultaneously issue the Final EIS and Record of Decision (ROD), pursuant to Pub. L. 112-141, 126 Stat. 405, Section 1319(b) and DOT's *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews* (http://www.dot.gov/sites/dot.gov/files/docs/MAP-21_1319_Final_Guidance.pdf), unless it is determined that statutory criteria or practicability considerations preclude simultaneous issuance.[45]

[45] 42 U.S.C. § 4332a(b). This contrasts with current CEQ implementing regulations, which state: "No decision on the proposed action shall be made or recorded … by a Federal agency until … thirty (30) days after publication of [EPA's notice of the filing of the final environmental impact statement]." 40 CFR § 1506.10. NHTSA has adhered to the requirement in the CEQ implementing regulations for prior EISs and rulemakings.

CHAPTER 2 PROPOSED ACTION AND ALTERNATIVES AND ANALYSIS METHODOLOGIES

2.1 Introduction

NEPA requires that, in the case of a major federal action, an agency must evaluate the environmental impacts of its proposed action and alternatives to that action.[1] An agency must rigorously explore and objectively evaluate all reasonable alternatives, including the alternative of taking no action. For alternatives an agency eliminates from detailed study, the agency must "briefly discuss the reasons for their having been eliminated."[2] The purpose of and need for the agency's action provides the foundation for determining the range of reasonable alternatives to be considered in its NEPA analysis.[3]

As explained in Chapter 1, NHTSA and EPA are proposing a second phase of standards to improve fuel efficiency for medium- and heavy-duty (HD) vehicles and reduce greenhouse gas (GHG) emissions, referred to as Phase 2 HD National Program standards. NHTSA's Proposed Action would establish Phase 2 HD standards that build on the Phase 1 fuel efficiency standards for HD engines and vehicles for model years (MYs) 2014–2018, in order to continue to increase HD fuel efficiency after 2018, in accordance with the Energy Policy and Conservation Act (EPCA), as amended by the Energy and Independence Security Act of 2007 (EISA). NHTSA developed the Proposed Action and alternatives in accordance with the EISA requirements discussed in Chapter 1, as well as relevant environmental and safety considerations. As with Phase 1, NHTSA's Phase 2 HD Fuel Efficiency Improvement Program rulemaking is being conducted in consultation with EPA and the U.S. Department of Energy (DOE).[4] Consistent with CEQ NEPA implementing regulations, this EIS compares the Proposed Action and a reasonable range of alternatives to Alternative 1 (No Action Alternative), which assumes that NHTSA and EPA would not issue a new rule regarding HD vehicle fuel efficiency and GHG emissions standards.[5] NEPA expressly requires agencies to consider a ''no action'' alternative in their NEPA analyses and to compare the effects of not taking action with the effects of action alternatives in order to demonstrate the impacts of the action alternatives.[6]

Under the No Action Alternative, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. Therefore, the fuel efficiency and GHG emissions standards for the final year of regulation for each segment under the Phase 1 program are assumed to continue indefinitely, and this serves as the basis for the No Action Alternative for the analysis of Phase 2 impacts. While the same technology penetrations are generally assumed in the Phase 2 No Action Alternative as anticipated under the Phase 1 fuel consumption and GHG standards, the values for No Action Alternative standards reported in this EIS are not directly comparable to values for the standards reported in the Phase 1 Final

[1] 42 U.S.C. § 4332(2)(C).
[2] 40 CFR §§ 1502.14(a), (d).
[3] 40 CFR § 1502.13. *See Vermont Yankee Nuclear Power Corp. v. Natural Res. Def. Council*, 435 U.S. 519, 551 (1978); *City of Alexandria v. Slater*, 198 F.3d 862, 867-69 (D.C. Cir. 1999), *cert. denied sub nom.*, 531 U.S. 820 (2000).
[4] *See* 49 U.S.C. § 32902(k)(2).
[5] 40 CFR § 1502.14(d).
[6] *See* 40 CFR §§ 1502.2(e), 1502.14(d). The Council on Environmental Quality (CEQ) has explained that "[T]he regulations require the analysis of the no action alternative even if the agency is under a court order or legislative command to act. This analysis provides a benchmark, enabling decision makers to compare the magnitude of environmental effects of the action alternatives. [*See* 40 CFR 1502.14(c).] …Inclusion of such an analysis in the EIS is necessary to inform Congress, the public, and the President as intended by NEPA. [See 40 CFR 1500.1(a).]" Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 *FR* 18026 (1981).

Rule and Final EIS because the agencies are proposing several test-procedure and minor regulatory changes that affect the way that standards are measured.

- First, compliance with overall HD vehicle standards is determined using the agencies' Greenhouse Gas Emissions Model (GEM) to simulate overall vehicle fuel efficiency given a set of vehicle component inputs. However, the proposed Phase 2 version of GEM will obtain higher (i.e., less favorable) CO_2 and fuel consumption values than the Phase 1 version of GEM because the Phase 2 drive cycles include road grade, which exists in the real-world, requiring the engine to operate at higher horsepower levels to maintain speed while climbing a hill.
- Second, to better reflect the aerodynamic performance of tractor-trailers, the agencies are also proposing to input the wind averaged coefficient of drag into Phase 2 GEM instead of the no-wind (zero yaw) value used in Phase 1.
- Third, the proposed Phase 2 program includes a more realistic and improved simulation of the transmission in GEM, which could increase CO_2 and fuel consumption relative to Phase 1.
- Fourth, the agencies recalculated APU deployment in tractors based on the current level of automatic engine shutdown and idle reduction technologies used by tractor manufacturers to comply with the 2014 model year fuel consumption and CO_2 standards.
- Finally, the Phase 2 No Action Alternative vocational vehicle standards also cannot be directly compared to Phase 1 standards because the Phase 2 program proposes further segmentation of vocational vehicle standards by fuel type and duty cycle.

For presentation in this chapter, NHTSA has recalculated the Phase 1 standards for the No Action Alternative of each segment using the new test procedures and regulatory changes in order to allow the reader to better understand the stringency levels of the action alternatives.

This chapter describes the action alternatives examined in this EIS, explains the methodologies and assumptions applied in estimating environmental impacts, and summarizes environmental impacts reported in subsequent EIS chapters. Readers may consult the NPRM & RIA documents for more detailed information on the individual alternatives, including the methodology by which they were developed, projected technologies, adoption rates, costs, etc. The remainder of this chapter is organized as follows:

- Section 2.2 describes the standards for HD engines, HD pickups and vans, vocational vehicles, tractors, and trailers under the No Action Alternative (Alternative 1), the Preferred Alternative (Alternative 3), and the other action alternatives (Alternatives 2, 4, and 5).
- Section 2.3 explains how direct and indirect impacts and cumulative impacts of each action alternative are measured against a No Action Alternative (Alternative 1), which assumes that neither NHTSA nor EPA would issue a rule regarding Phase 2 HD fuel consumption standards or GHG emissions standards.
- Section 2.4 summarizes environmental impacts reported in subsequent EIS chapters.

2.2 Proposed Standards and Alternatives

The HD vehicle sector is often subdivided by gross vehicle weight rating (GVWR), which is a measure of the combined curb (empty) weight and cargo carrying capacity of the truck. Table 2.2-1 outlines the GVWR classifications commonly used for a variety of purposes by businesses and federal agencies.

Table 2.2-1. HD Vehicle Weight Classification

Class	2b	3	4	5	6	7	8
GVWR (pounds)	8,501–10,000	10,001–14,000	14,001–16,000	16,001–19,500	19,501–26,000	26,001–33,000	> 33,001

In the framework of these GVWR classifications, HD vehicles refer to Classes 2b–8 and the engines that power those vehicles. HD vehicles often vary widely in configuration (i.e., are composed of different vehicle parts combined in different ways). In setting Phase 1 HD vehicle standards, EPA and NHTSA divided the industry into discrete categories—HD pickups and vans, vocational vehicles, and combination tractors—based on the relative homogeneity among vehicles within each category. The agencies established separate fuel consumption standards for each of these HD vehicle categories. The agencies also decided that setting separate standards for the engines that power combination tractors and vocational vehicles, as well as complete vehicle fuel efficiency standards for each category of HD vehicles best met the purpose and need for that action. NHTSA believes that this same general structure of setting engine standards for vocational vehicles and combination tractors; separate HD vehicle fuel consumption standards for HD pickups and vans, vocational vehicles, and combination tractors; and adding, for the first time, fuel consumption standards for certain trailers used in combination with the Classes 7–8 tractors best meets the purpose and need for Phase 2 standards, and allows for the achievement of "maximum feasible improvement" in HD vehicle fuel efficiency.

HD pickups and vans (Classes 2b–3) are used chiefly as work trucks and vans, and as shuttle vans, as well as for personal transportation. Other HD vehicles are used for carrying cargo and/or performing specialized tasks. "Vocational" vehicles, which span Classes 2b–8, vary widely in size, including smaller and larger van trucks, utility "bucket" trucks, tank trucks, refuse trucks, urban and over-the-road buses, fire trucks, flat-bed trucks, and dump trucks, among others. Classes 7–8 combination tractor-trailers (some equipped with sleeper cabs and some not) are primarily used for freight transportation.

The variability of the HD vehicle fleet is reflected in different proposed fuel consumption standards for HD engines and different types of HD vehicles (specified as gallons of fuel per horsepower-hour [gal/100 bhp-hr] for engines, gal/100 miles for HD pickups and vans, and gallons of fuel per 1,000 ton payload mile [gal/1,000 ton-miles] for tractor-trailers and vocational vehicles). Fuel consumption standards, including engine standards, are based on specific drive cycles chosen based on the typical expected use of each vehicle. The drive cycle used in compliance testing has significant consequences for the technology that will be employed to achieve a standard, as well as the ability of the technology to achieve real-world reductions in fuel consumption. Therefore, compliance testing for fuel consumption standards varies to reflect the anticipated drive cycles in different segments of the HD vehicle market.

The NPRM specifies Phase 2 proposed standards and compliance testing requirements for HD engines, HD pickups and vans, vocational vehicles, tractors, and trailers. In this EIS, Alternative 3, the Preferred Alternative, refers to the same standards and testing requirements specified as the proposed standards in the NPRM.[7] Alternative 2 is less stringent than the Preferred Alternative (i.e., would require less fuel efficiency improvement than Alternative 3), Alternative 4 is more stringent than Alternative 3, and Alternative 5 is the most stringent action alternative examined in this analysis. For a full discussion of the development of the proposed standards and alternatives, as well as their assumptions and stringency levels, consult the NPRM and Draft RIA. Those discussions are incorporated by reference herein.

[7] The analysis in this EIS specifically corresponds to "Analysis 1a" results in the NPRM.

The remainder of this section is organized into five subsections that describe the alternative standards examined by NHTSA and EPA for different segments of the HD vehicle market: HD engines, Classes 7–8 tractors, trailers, Classes 2b–8 vocational vehicles, and Classes 2b–3 HD pickups and vans. These five subsections detail the performance standards for different HD vehicle market segment under the No Action Alternative and each of the action alternatives.

2.2.1 HD Engines for Vocational Vehicles and Tractors

The Phase 1 program set engine performance standards and specified engine test procedures for Classes 2b–8 vocational vehicles and tractors (HD pickups and vans are regulated as complete vehicles, as described in Section 2.2.5). HD engine manufacturers are responsible for ensuring that each engine meets the applicable vehicle class engine performance standard when tested in accordance with the specified engine test procedure.

For the most part, the proposed Phase 2 engine standards are a continuation of the Phase 1 program, but with more stringent standards for diesel (compression-ignition) engines, and important changes related to the test procedures and compliance provisions. Engine manufacturers can improve engine performance by applying combinations of fuel efficiency improvement technologies to the engine.

The proposed diesel engine test procedure relies on two separate engine test cycles. The first is the Heavy-duty Federal Test Procedure (HD FTP) that includes transient operation typified by frequent accelerations and decelerations, similar to urban or suburban driving. The second is the Supplemental Engine Test (SET), which includes 13 steady-state test points, similar to highway cruise operation and other nominally steady-state operation. The gasoline (spark-ignition) engine test procedure relies on a single engine test cycle: a gasoline version of HD FTP. The agencies are not proposing changes to the gasoline engine test procedures or new more stringent standards for gasoline vocational engines, as discussed below. The specific engine performance standards examined vary with the intended engine application by vehicle class and the type of fuel used, as shown below in Table 2.2.1-1.

Table 2.2.1-1. HD Engine Regulatory Subcategories

Engine Category	Intended Application
Light Heavy-Duty (LHD) Diesel	Classes 2b–5 vehicles (8,501 through 19,500 pounds GVWR)
Medium Heavy-Duty (MHD) Diesel	Classes 6–7 vehicles (19,501 through 33,000 pounds GVWR)
Heavy Heavy-Duty (HHD) Diesel	Class 8 vehicles (33,001 pounds and greater GVWR)
Gasoline	Primarily for vehicles less than 14,000 pounds, including almost 50% of HD pickups and vans, and less than 10% of vocational vehicles.

2.2.1.1 Alternative 1 - No Action HD Engines for Vocational Vehicles and Tractors

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. As a result, Phase 1 HD engine standards and test procedures would remain in effect indefinitely at their MY 2017 levels until amended by a future rulemaking action. Table 2.2.1-2 shows the MY 2017 Phase 1 standards for diesel engines used in Classes 7–8 tractors, which would remain in effect in 2018 and beyond under the Phase 2 No Action Alternative.

Table 2.2.1-2. Alternative 1 - No Action HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2017 and Later	CO_2 (g/bhp-hr)	487	460
	Fuel Consumption (gallon/100 bhp-hr)	4.78	4.52

Notes:
bhp-hr = brake horsepower-hour

Table 2.2.1-3 shows MY 2017 Phase 1 standards for diesel engines used in Classes 2b–8 vocational vehicles, which would remain in effect in 2018 and beyond under the Phase 2 No Action Alternative.

Table 2.2.1-3. Alternative 1 - No Action HD Tractor Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2017 and Later	CO_2 (g/bhp-hr)	576	576	555
	Fuel Consumption (gallon/100 bhp-hr)	5.57	5.57	5.45

Notes:
bhp-hr = brake horsepower-hour

The Phase 1 rule also set a fuel consumption standard of 7.05 gallon/100 bhp-hr and CO_2 standard of 627 g/bhp-hr for MY 2016 and beyond for gasoline engines used in Classes 2b–8 vocational vehicles. This gasoline engine standard would apply under the Phase 2 No Action Alternative and under all of the Phase 2 action alternatives. The number of gasoline (spark-ignited) vocational vehicles sold is small, and these vehicles commonly share most of the same technology as equivalent complete pickups or vans, including the powertrain. The resulting market structure leads manufacturers of HD gasoline engines to have little market incentive to develop separate technology for vocational engines that are engine-certified, and engine technologies that are used in engine-certified vocational engines are also projected to be used on complete HD pickups and vans. Therefore, the agencies are continuing the Phase 1 standard for spark-ignited gasoline engines used in vocational vehicles, given the relatively small improvement projected with new standards, and the likelihood that most or all of this improvement would result anyway from the complete pickup and van standards and the vocational vehicle-based standards.

Fuel consumption and emissions standards for engines used in Classes 7–8 tractors do not cover gasoline (or LHD diesel) engines, as those are not used in Classes 7–8 tractors. Therefore, the action alternative standards for HD engines for vocational vehicles and tractors, discussed below, focus on diesel engine standards, because the small number of gasoline engines used in vocational vehicles and tractors would be subject to the same standards under the No Action and action alternatives.

2.2.1.2 Alternative 2 HD Engines for Vocational Vehicles and Tractors

Under Alternative 2, diesel engines to be installed in Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.1-4.

Table 2.2.1-4. Alternative 2 HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	481	455
	Fuel Consumption (gallon/100 bhp-hr)	4.7250	4.4695
2024 and Later	CO_2 (g/bhp-hr)	471	445
	Fuel Consumption (gallon/100 bhp-hr)	4.6267	4.3713

Notes:
bhp-hr = brake horsepower-hour

Table 2.2.1-5 presents the Alternative 2 fuel consumption and emissions standards for diesel engines fitted into vocational vehicles.

Table 2.2.1-5. Alternative 2 HD Vocational Vehicle Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	571	571	550
	Fuel Consumption (gallon/100 bhp-hr)	5.6090	5.6090	5.4028
2024 and Later	CO_2 (g/bhp-hr)	559	559	539
	Fuel Consumption (gallon/100 bhp-hr)	5.4912	5.4912	5.2947

Notes:
bhp-hr = brake horsepower-hour

2.2.1.3 Alternative 3 - Preferred HD Engines for Vocational Vehicles and Tractors

For diesel engines to be installed in Classes 7–8 tractors, the agencies are proposing the Alternative 3 (Preferred Alternative) standards shown in Table 2.2.1-6. The Preferred Alternative MY 2027 standards for engines installed in tractors would require engine manufacturers to achieve, on average, a 4.2 percent reduction in fuel consumption and CO_2 emissions beyond the Phase 1 standard, and interim engine standards in MY 2021 and MY 2024 that would require diesel engine manufacturers to achieve, on average, 1.5 percent and 3.7 percent reductions in fuel consumption and CO_2 emissions, respectively.

Table 2.2.1-6. Alternative 3 - Preferred HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	479	453
	Fuel Consumption (gallon/100 bhp-hr)	4.7053	4.4499
2024–2026	CO_2 (g/bhp-hr)	469	443
	Fuel Consumption (gallon/100 bhp-hr)	4.6071	4.3517
2027 and Later	CO_2 (g/bhp-hr)	466	441
	Fuel Consumption (gallon/100 bhp-hr)	4.5776	4.3320

Notes:
bhp-hr = brake horsepower-hour

For diesel engines fitted into vocational vehicles, the agencies are proposing MY 2027 standards that would require engine manufacturers to achieve, on average, a 4.0 percent reduction in CO_2 emissions and fuel consumption beyond the Phase 1 standard, and interim engine standards in MY 2021 and MY 2024 that would require diesel engine manufacturers to achieve, on average, 2.0 percent and 3.5 percent reductions in fuel consumption and CO_2 emissions, respectively. Table 2.2.1-7 presents the Preferred Alternative CO_2 and fuel consumption standards the agencies propose for diesel engines to be installed in vocational vehicles. The first set of standards would take effect with MY 2021, and the second set would take effect with MY 2024.

Table 2.2.1-7. Alternative 3 - Preferred HD Vocational Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	565	565	544
	Fuel Consumption (gallon/100 bhp-hr)	5.5501	5.5501	5.3438
2024–2026	CO_2 (g/bhp-hr)	556	556	536
	Fuel Consumption (gallon/100 bhp-hr)	5.4617	5.4617	5.2652
2027 and Later	CO_2 (g/bhp-hr)	553	553	533
	Fuel Consumption (gallon/100 bhp-hr)	5.4322	5.4322	5.2358

Notes:
bhp-hr = brake horsepower-hour

2.2.1.4 Alternative 4 HD Engines for Vocational Vehicles and Tractors

Alternative 4 engine standards for vocational vehicles and tractors are the same as under the Preferred Alternative but would require that these standards be met sooner. MY 2024 Alternative 4 standards are essentially identical to those for MY 2027 under Alternative 3. Under Alternative 4, diesel engines to be installed in Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.1-8.

Table 2.2.1-8. Alternative 4 HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	477	451
	Fuel Consumption (gallon/100 bhp-hr)	4.6857	4.4303
2024 and Later	CO_2 (g/bhp-hr)	466	441
	Fuel Consumption (gallon/100 bhp-hr)	4.5776	4.3320

Notes:
bhp-hr = brake horsepower-hour

Table 2.2.1-9 presents the Alternative 4 CO_2 and fuel consumption standards for diesel engines to be installed in vocational vehicles.

Table 2.2.1-9. Alternative 4 HD Vocational Vehicle Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	562	562	541
	Fuel Consumption (gallon/100 bhp-hr)	5.5206	5.5206	5.3143
2024 and Later	CO_2 (g/bhp-hr)	553	553	533
	Fuel Consumption (gallon/100 bhp-hr)	5.4322	5.4322	5.2358

Notes:
bhp-hr = brake horsepower-hour

2.2.1.5 Alternative 5 HD Engines for Vocational Vehicles and Tractors

Under Alternative 5, diesel engines to be installed in Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.1-10.

Table 2.2.1-10. Alternative 5 HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	474	448
	Fuel Consumption (gallon/100 bhp-hr)	4.6562	4.4008
2024 and Later	CO_2 (g/bhp-hr)	464	438
	Fuel Consumption (gallon/100 bhp-hr)	4.5580	4.3026

Notes:
bhp-hr = brake horsepower-hour

Table 2.2.1-11 presents the Alternative 5 fuel consumption and emissions standards for diesel engines fitted into vocational vehicles.

Table 2.2.1-11. Alternative 5 HD Vocational Vehicle Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	559	559	538
	Fuel Consumption (gallon/100 bhp-hr)	5.4912	5.4912	5.2849
2024 and Later	CO_2 (g/bhp-hr)	550	550	530
	Fuel Consumption (gallon/100 bhp-hr)	5.4028	5.4028	5.2063

Notes:
bhp-hr = brake horsepower-hour

2.2.2 Classes 7–8 Tractors

Combination tractors consume the largest fraction of fuel among the HD vehicle categories. Tractors also offer significant potential for fuel savings due to the high annual mileage and average vehicle speeds within this category as compared to annual mileage and average speeds or duty cycles of other HD vehicle categories. In addition to the engine standards described above, the Phase 2 standards would require Classes 7–8 tractor manufacturers to meet an overall vehicle performance standard by making various non-engine fuel saving technology improvements (e.g., by using a combination of technologies such as improving aerodynamics, lowering tire rolling resistance, decreasing vehicle mass (weight), reducing fuel use at idle, improving efficiency of transmissions, or other technologies).

The alternative standards examined for Classes 7–8 tractors vary depending on whether it is a “day cab” or “sleeper cab” (sleeper cabs provide overnight accommodations for drivers). Tractors with sleeper cabs tend to have greater empty curb weight than tractors with day cabs due to the larger cab accommodations, and some technologies (e.g., extended idle reduction) are appropriate for tractors with sleeper cabs but less so for day cabs. Standards for Class 8 tractors with day cabs versus sleeper cabs also reflect different drive cycles. Day cab tractors have a larger percentage of their drive cycle weighted to transient (urban) driving and sleeper cab tractors have a larger percentage of their drive cycle weighted to a cruising speed of 65 miles per hour. Standards for Classes 7–8 tractors also vary with the height of the roof, designed to correspond to the height of the trailer, because roof height significantly affects aerodynamic drag, which is an important determinant of tractor fuel efficiency.

Compliance with the overall vehicle standards for Classes 7–8 tractors would be determined using GEM to simulate overall vehicle fuel efficiency given a set of vehicle component inputs. Using this approach, the Classes 7–8 vehicle manufacturers would supply certain vehicle characteristics that would serve as GEM inputs. Thus, vehicle manufacturers could make any combination of improvements using non-engine technologies that they believe would best achieve the Classes 7–8 tractor overall fuel consumption standards.

2.2.2.1 Alternative 1 - No Action Classes 7–8 Tractors

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. As a result, Phase 1 tractor standards and test procedures would remain in effect indefinitely at their MY 2017 levels until amended by a future rulemaking action. For ease of comparison with the Phase 2 proposed standards and alternatives, the Phase 1 standards were recalculated to reflect revised test procedures described above. Under Alternative 1, these recalculated standards serve as the baseline, and are expected to achieve equivalent environmental impacts as the Phase 1 tractor standards and test procedures if left unchanged. Table 2.2.2-1 shows the recalculated MY 2017 and beyond Phase 1 standards for Classes 7–8 tractors, which would remain in effect in 2018 and beyond under the Phase 2 No Action Alternative.

Table 2.2.2-1. Alternative 1 - No Action Classes 7–8 Tractor Standards

2017 Model Year and later CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	107	86	79
Mid Roof	118	93	87
High Roof	121	95	88
2017 Model Year and later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	10.5	8.4	7.8
Mid Roof	11.6	9.1	8.5
High Roof	11.9	9.3	8.6

2.2.2.2 Alternative 2 Classes 7–8 Tractors

Under Alternative 2, Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.2-2.

Table 2.2.2-2. Alternative 2 Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	102	82	73
Mid Roof	112	88	81
High Roof	114	90	80
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	10.0196	8.055	7.1709
Mid Roof	11.0020	8.6444	7.9568
High Roof	11.1984	8.8409	7.8585
2024 Model Year and later CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	97	77	68
Mid Roof	107	84	76
High Roof	109	85	74
2024 Model Year and later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	9.5285	7.5639	6.6798
Mid Roof	10.5108	8.2515	7.4656
High Roof	10.7073	8.3497	7.2692

2.2.2.3 Alternative 3 - Preferred Classes 7–8 Tractors

For Classes 7–8 tractors, the agencies are proposing the Alternative 3 (Preferred Alternative) CO_2 and fuel consumption standards shown in Table 2.2.2-3.

Table 2.2.2-3. Alternative 3 - Preferred Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	97	78	70
Mid Roof	107	84	78
High Roof	109	86	77
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	9.5285	7.6621	6.8762
Mid Roof	10.5108	8.2515	7.6621
High Roof	10.7073	8.4479	7.5639
2024–2026 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	90	72	64
Mid Roof	100	78	71
High Roof	101	79	70
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	8.8409	7.0727	6.2868
Mid Roof	9.8232	7.6621	6.9745
High Roof	9.9214	7.7603	6.8762
2027 Model Year and later CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	87	70	62
Mid Roof	96	76	69
High Roof	96	76	67
2027 Model Year and later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	8.5462	6.8762	6.0904
Mid Roof	9.4303	7.4656	6.7780
High Roof	9.4303	7.4656	6.5815

2.2.2.4 Alternative 4 Classes 7–8 Tractors

Under Alternative 4, Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.2-4. Alternative 4 MY 2024 standards are the same as the Preferred Alternative MY 2027 standards.

Table 2.2.2-4. Alternative 4 Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	92	74	66
Mid Roof	102	81	74
High Roof	104	82	73
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	9.0373	7.2692	6.4833
Mid Roof	10.0196	7.9568	7.2692
High Roof	10.2161	8.0550	7.1709
2024 Model Year and later CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	87	70	62
Mid Roof	96	76	69
High Roof	96	76	67
2024 Model Year and later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	8.5462	6.8762	6.0904
Mid Roof	9.4303	7.4656	6.7780
High Roof	9.4303	7.4656	6.5815

2.2.2.5 Alternative 5 Classes 7–8 Tractors

Under Alternative 5, Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.2-5.

Table 2.2.2-5. Alternative 5 Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	87	70	63
Mid Roof	96	75	71
High Roof	98	77	70
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	8.5462	6.8762	6.1886
Mid Roof	9.4303	7.3674	6.9745
High Roof	9.6267	7.5639	6.8762
2024 Model Year and later CO_2 Grams per Ton-Mile			
	Day Cab		**Sleeper Cab**
	Class 7	**Class 8**	**Class 8**
Low Roof	82	65	58
Mid Roof	91	71	64
High Roof	92	72	63

2024 Model Year and later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	8.0550	6.3851	5.6974
Mid Roof	8.9391	6.9745	6.2868
High Roof	9.0373	7.0727	6.1886

2.2.3 Trailers

The Phase 2 NPRM includes, for the first time, proposed fuel consumption standards for new trailers that would begin with a voluntary three year program, followed by a mandatory program phasing in over a period of seven years. EPA's proposed GHG emissions standards for new trailers would be mandatory from the beginning. Although the agencies are proposing new fuel consumption and CO_2 standards for trailers separately from tractors, the numerical level of the trailer standards is in relation to "standard" reference tractors in recognition of their interrelatedness. In other words, the regulatory standards refer to the simulated fuel consumption and emissions of a standard tractor pulling the trailer being certified. The trailer industry produces different trailer designs for different applications, and the proposed standards would apply (in one form or another) to most types of trailers. The most comprehensive requirements would apply to box trailers, including refrigerated and non-refrigerated (dry) vans. Box trailers are the largest trailer category with the highest annual vehicle miles traveled, which offers the greatest potential for fuel consumption and CO_2 reductions. More modest requirements are proposed for all highway non-box trailers that would not require the use of aerodynamic devices, but could be met by adopting low rolling resistance tires and automatic tire inflation systems. Non-box trailer tires would need to achieve a coefficient of rolling resistance of 5.1 in MY 2018 (voluntary in the NHTSA program until MY 2021) and 4.7 for MY 2024 and later model years.

Differences in the numerical values of box trailer standards among trailer subcategories under each alternative reflect differences in the tractor-trailer characteristics, as well as differences in the default payloads, in the vehicle simulation model used to develop the trailer standards. Therefore, lower values do not necessarily indicate more stringent standards. For instance, the Preferred Alternative standards for dry and refrigerated vans of the same length have the same stringency through MY 2026, but the standards recognize differences in trailer weight and aerodynamic performance of refrigerated vans. Trailers of the same type but different length also differ in weight, as well as in the number of axles (and tires), tractor type, payload and aerodynamic performance.

2.2.3.1 Alternative 1 - No Action Trailers

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. There were no trailer standards under the Phase 1 program, so the Phase 2 No Action Alternative for trailers reflects the performance levels (simulated fuel consumption and emissions of a standard tractor pulling the trailer) that the agencies expect box trailers would achieve in the absence of any federal fuel consumption or GHG standards.

2.2.3.2 Alternative 2 Trailers

Under Alternative 2, box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-2 (simulated fuel consumption and emissions of a standard tractor pulling the trailer). Alternative 2 trailer standards would apply to only 53-foot box trailers and could be achieved by using less advanced aerodynamic and tire technologies than would be required by other action alternatives.

Table 2.2.3-2. Alternative 2 HD Box Trailer Standards

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	83	147	84	151
	Gallons per 1,000 Ton-Mile (*Voluntary*)	8.1532	14.4401	8.2515	14.8330
2021–2023	CO_2 Grams per Ton-Mile	82	147	84	151
	Gallons per 1,000 Ton-Mile	8.0550	14.4401	8.2515	14.8330
2024 and Later	CO_2 Grams per Ton-Mile	81	147	83	151
	Gallons per 1,000 Ton-Mile	7.9568	14.4401	8.1532	14.8330

2.2.3.3 Alternative 3 - Preferred Trailers

Under Alternative 3, the Preferred Alternative, box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-3 (simulated fuel consumption and emissions of a standard tractor pulling the trailer).

Table 2.2.3-3. Alternative 3 - Preferred HD Box Trailer Standards

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	83	144	84	147
	Gallons per 1,000 Ton-Mile (*Voluntary*)	8.1532	14.1454	8.2515	14.4401
2021–2023	CO_2 Grams per Ton-Mile	81	142	82	146
	Gallons per 1,000 Ton-Mile	7.9568	13.9489	8.0550	14.3418
2024–2026	CO_2 Grams per Ton-Mile	79	141	81	144
	Gallons per 1,000 Ton-Mile	7.7603	13.8507	7.9568	14.1454
2027 and Later	CO_2 Grams per Ton-Mile	77	140	80	144
	Gallons per 1,000 Ton-Mile	7.5639	13.7525	7.8585	14.1454

2.2.3.4 Alternative 4 Trailers

Alternative 4 standards for trailers are the same as under the Preferred Alternative but on an accelerated schedule, shown in Table 2.2.3-4.

Table 2.2.3-4. Alternative 4 HD Box Trailer Standards

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	83	144	84	147
	Gallons per 1,000 Ton-Mile (*Voluntary*)	8.1532	14.1454	8.2515	14.4401
2021–2023	CO_2 Grams per Ton-Mile	80	142	81	145
	Gallons per 1,000 Ton-Mile	7.8585	13.9489	7.9568	14.2436
2024 and Later	CO_2 Grams per Ton-Mile	77	140	80	144
	Gallons per 1,000 Ton-Mile	7.5639	13.7525	7.8585	14.1454

2.2.3.5 Alternative 5 Trailers

Under Alternative 5, box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-5 (simulated fuel consumption and emissions of a standard tractor pulling the trailer).

Table 2.2.3-5. Alternative 5 HD Box Trailer Standards

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	82	144	83	147
	Gallons per 1,000 Ton-Mile (*Voluntary*)	8.0550	14.1454	8.1532	14.4401
2021–2023	CO_2 Grams per Ton-Mile	79	142	81	145
	Gallons per 1,000 Ton-Mile	7.7603	13.9489	7.9568	14.2436
2024 and Later	CO_2 Grams per Ton-Mile	76	140	80	143
	Gallons per 1,000 Ton-Mile	7.4656	13.7525	7.8585	14.0472

2.2.4 Classes 2–8 Vocational Vehicles

Fuel consumption standards for vocational vehicles vary by vehicle class (Classes 2b–5, Classes 6–7, and Class 8), ignition type and engine fuel (spark-ignited [SI] gasoline, and combustion-ignited [CI] diesel), and duty cycle: Regional, Multi-Purpose, and Urban. The three duty cycles have different weightings for an idle cycle, highway cruise cycles, and ARB Transient cycle. Compliance with vocational vehicle standards would be determined by GEM simulation of vehicle fuel efficiency given a set of vehicle component inputs. Thus, vehicle manufacturers could make any combination of improvements that they believe would best achieve the vocational vehicle standards.

2.2.4.1 Alternative 1 - No Action Classes 2–8 Vocational Vehicles

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. As a result, Phase 1 vocational vehicle standards and test procedures would remain in effect indefinitely at their MY 2017 levels until amended by a future rulemaking action. For ease of comparison with the Phase 2 proposed standards and alternatives, the Phase 1 standards were recalculated to reflect revised test procedures and the new subcategories (i.e., duty cycles) described above. Under Alternative 1, these recalculated standards serve as the baseline, and are expected to achieve equivalent environmental impacts as the Phase 1 vocational vehicle standards and test procedures if left unchanged. Table 2.2.4-1 shows the recalculated MY 2017 and beyond Phase 1 standards for Classes 2–8 diesel (CI) vocational vehicles, and Table 2.2.4-2 shows the recalculated MY 2017 and beyond Phase 1 standards for gasoline (SI) vocational vehicles. These standards would remain in effect in 2018 and beyond under the Phase 2 No Action Alternative.

Table 2.2.4-1. Alternative 1 - No Action Diesel (CI) Vocational Vehicle Standards

CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	316	201	212
Multi-Purpose	325	203	214
Regional	339	199	203
Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	31.0413	19.7446	20.8251
Multi-Purpose	31.9253	19.9411	21.0216
Regional	33.3006	19.5481	19.9411

Table 2.2.4-2. Alternative 1 - No Action Gasoline (SI) Vocational Vehicle Standards

CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	334	213	224
Multi-Purpose	344	215	226
Regional	358	211	214
Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	37.5830	23.9676	25.2054
Multi-Purpose	38.7082	24.1926	25.4304
Regional	40.2836	23.7425	24.0801

2.2.4.2 Alternative 2 Classes 2–8 Vocational Vehicles

Under Alternative 2, Classes 2–8 vocational vehicles would be subject to the fuel efficiency and emissions standards shown in Table 2.2.4-3 and 2.2.4-4, for diesel and gasoline vehicles respectively. Alternative 2 standards for vocational vehicles could be met without any use of strong hybrids, and with lower adoption rates of other technologies used to meet other action alternative standards.

Table 2.2.4-3. Alternative 2 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	305	194	205
Multi-Purpose	314	196	207
Regional	328	192	195
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	29.9468	19.0615	20.0969
Multi-Purpose	30.8574	19.2642	20.2999
Regional	32.1726	18.8587	19.1834
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	296	187	198
Multi-Purpose	304	189	200
Regional	317	185	190
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	29.0602	18.3233	19.4746
Multi-Purpose	29.8789	18.5280	19.6796
Regional	31.1068	18.2209	18.6547

Table 2.2.4-4. Alternative 2 Gasoline (SI) Vocational Vehicle Standards

2021-2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	330	210	221
Multi-Purpose	339	212	223
Regional	353	207	211
2021-2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	37.0853	23.5770	24.8811
Multi-Purpose	38.1283	23.8092	25.1137
Regional	39.7508	23.3446	23.7185
2027 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	325	205	217
Multi-Purpose	334	207	219
Regional	348	204	208
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	36.5703	23.0998	24.4215
Multi-Purpose	37.6252	23.3344	24.6563
Regional	39.1490	22.9826	23.3648

2.2.4.3 Alternative 3 - Preferred Classes 2–8 Vocational Vehicles

Tables 2.2.4-5 and 2.2.4-6 show the Alternative 3 (Preferred Alternative) vocational vehicles standards for CI diesel and SI gasoline vehicles, respectively.

Table 2.2.4-5. Alternative 3 - Preferred Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	296	188	198
Multi-Purpose	305	190	200
Regional	318	186	189
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	29.0766	18.4676	19.4499
Multi-Purpose	29.9607	18.6640	19.6464
Regional	31.2377	18.2711	18.5658
2024–2026 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	284	179	190
Multi-Purpose	292	181	192
Regional	304	178	182
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	27.8978	17.5835	18.6640
Multi-Purpose	28.6837	17.7800	18.8605
Regional	29.8625	17.4853	17.8782

2027 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	272	172	182
Multi-Purpose	280	174	183
Regional	292	170	174
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	26.7191	16.8959	17.8782
Multi-Purpose	27.5049	17.0923	17.9764
Regional	28.6837	16.6994	17.0923

Table 2.2.4-6. Alternative 3 - Preferred Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	320	203	214
Multi-Purpose	329	205	216
Regional	343	201	204
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	36.0077	22.8424	24.0801
Multi-Purpose	37.0204	23.0674	24.3052
Regional	38.5957	22.6173	22.9549
2024–2026 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	312	197	208
Multi-Purpose	321	199	210
Regional	334	196	199
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	35.1075	22.1672	23.4050
Multi-Purpose	36.1202	22.3923	23.6300
Regional	37.5830	22.0547	22.3923
2027 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	299	189	196
Multi-Purpose	308	191	198
Regional	321	187	188
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	33.6446	21.2670	22.0547
Multi-Purpose	34.6574	21.4921	22.2797
Regional	36.1202	21.0420	21.1545

2.2.4.4 Alternative 4 Classes 2–8 Vocational Vehicles

Alternative 4 standards for vocational vehicles are the same as under the Preferred Alternative but would require that these standards be met sooner, as shown in Tables 2.2.4-7 and 2.2.4-8.

Table 2.2.4-7. Alternative 4 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	288	183	193
Multi-Purpose	297	185	196
Regional	309	181	185
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	28.2908	17.9764	18.9587
Multi-Purpose	29.1749	18.1729	19.2534
Regional	30.3536	17.7800	18.1729
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	272	172	182
Multi-Purpose	280	174	183
Regional	292	170	174
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	26.7191	16.8959	17.8782
Multi-Purpose	27.5049	17.0923	17.9764
Regional	28.6837	16.6994	17.0923

Table 2.2.4-8. Alternative 4 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	313	199	210
Multi-Purpose	323	201	212
Regional	336	197	201
2021–-2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	35.2200	22.3923	23.6300
Multi-Purpose	36.3452	22.6173	23.8551
Regional	37.8080	22.1672	22.6173
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	299	189	196
Multi-Purpose	308	191	198
Regional	321	187	188
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	33.6446	21.2670	22.0547
Multi-Purpose	34.6574	21.4921	22.2797
Regional	36.1202	21.0420	21.1545

2.2.4.5 Alternative 5 Classes 2–8 Vocational Vehicles

Under Alternative 5, Classes 2–8 vocational vehicles would be subject to the fuel efficiency and emissions standards shown in Table 2.2.4-9 and 2.2.4-10, for diesel and gasoline vehicles respectively.

Table 2.2.4-9. Alternative 5 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	270	171	180
Multi-Purpose	279	173	181
Regional	290	169	172
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	26.5560	16.8009	17.6505
Multi-Purpose	27.3635	16.9796	17.8288
Regional	28.5298	16.6222	16.8482
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	253	159	169
Multi-Purpose	260	161	170
Regional	271	158	161
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	24.8577	15.6298	16.5564
Multi-Purpose	25.5579	15.8044	16.7308
Regional	26.6083	15.5425	15.8594

Table 2.2.4-10. Alternative 5 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	292	185	194
Multi-Purpose	300	186	196
Regional	313	183	185
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	32.8863	20.7809	21.8523
Multi-Purpose	33.8112	20.9856	22.0566
Regional	35.2499	20.5761	20.8312
2027 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	278	175	185
Multi-Purpose	286	177	186
Regional	298	174	177
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	31.2817	19.7042	20.7621
Multi-Purpose	32.1840	19.9043	20.9617
Regional	33.4874	19.6042	19.8637

2.2.5 Classes 2b–3 Pickups and Vans

For HD pickups and vans, vehicle testing would be conducted on chassis dynamometers using the drive cycles from the EPA FTP (or ''city'' test) and Highway Fuel Economy Test (HFET or ''highway'' test). The FTP and HFET results would be weighted by 55 percent and 45 percent, respectively, and then averaged to calculate a combined cycle result. The 55/45 cycle weightings are the same as for the light-duty CAFE program, as NHTSA and EPA believe the real-world driving patterns for HD pickups and vans are similar to those of light-duty trucks. Compliance with fuel consumption standards for HD pickups and vans will continue to be determined through a fleet averaging process similar to the process used in determining passenger car and light truck compliance with CAFE standards.

The fuel consumption standards for HD pickups and vans are based on a "work factor" attribute that combines vehicle payload capacity and vehicle towing capacity, in pounds, with an additional fixed adjustment for four-wheel drive (4wd) vehicles. Fuel consumption targets would be determined for each vehicle with a unique work factor. These targets would then be production-weighted and summed to derive a manufacturer's annual fleet average standards.

HD pickup and van standards vary in stringency across action alternatives, but all of the standards are based on a functional relationship between fuel economy and GHG emissions to a vehicle's work factor, as described above. The No Action Alternative assumes Phase 1 HD pickup and van standards and test procedures would remain in effect indefinitely at their MY 2018 or MY 2019 levels (depending upon the implementation schedule chosen by manufacturers, as described in the Phase 1 Final Rule) until amended by a future rulemaking action. The action alternatives considered represent different rates of annual increase in fuel efficiency stringency and associated outcomes, and Alternatives 2, 4, and 5 would only increase stringency through 2025, as shown in Table 2.2.5-1.

Table 2.2.5-1. Summary of Action Alternatives Examined for Phase 2 HD Pickup and Van Standards

	Alt. 2	Alt. 3 - Preferred	Alt. 4	Alt. 5
Annual Stringency Increase	2.0%/y	2.5%/y	3.5%/y	4.0%/y
Stringency Increase Through MY	2025	2027	2025	2025
Total Stringency Increase	9.6%	16.2%	16.3%	18.5%
Average Fuel Economy (miles per gallon) in Final MY of Stringency Increase				
Required	19.04	20.57	20.57	21.14
Achieved	19.14	20.61	20.83	21.27
Average Fuel Consumption (gallons /100 mi.) in Final MY of Stringency Increase				
Required	5.25	4.86	4.86	4.73
Achieved	5.22	4.85	4.80	4.70
Average Greenhouse Gas Emissions (g/mi) in Final MY of Stringency Increase				
Required	495	458	458	446
Achieved	491	458	453	444

Figures 2.2.5-1 and 2.2.5-2 illustrate the functional relationship between the work factor for HD pickups and vans and the corresponding fuel consumption targets under the Phase 2 Preferred Alternative for HD pickups and vans, specified in gal/100 miles (specific formulas for calculating work factors for HD pickups and vans under the action alternatives are presented in the Section IV of the NPRM).
Figure 2.2.5-1 shows that fuel consumption target standards for HD diesel pickups and vans for MY 2027 would be approximately 3.7 to 5.0 gal/100 miles, depending on the calculated work factor.

Figure 2.2.5-2 shows that the fuel consumption target standards for HD gasoline pickups and vans for MY 2027 would be approximately 4.4 to 6.2 gal/100 miles, depending on the calculated work factor.

Figure 2.2.5-1. Alternative 3 - Preferred Phase 2 HD Fuel Consumption and CO_2 Standards for Diesel HD Pickups and Vans

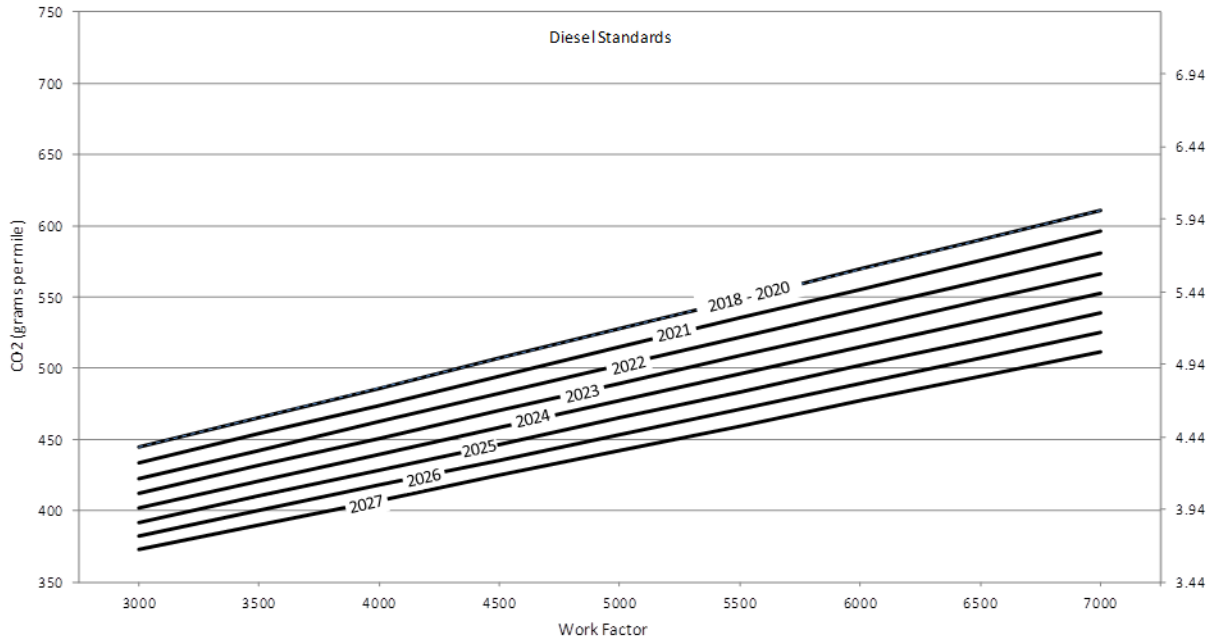
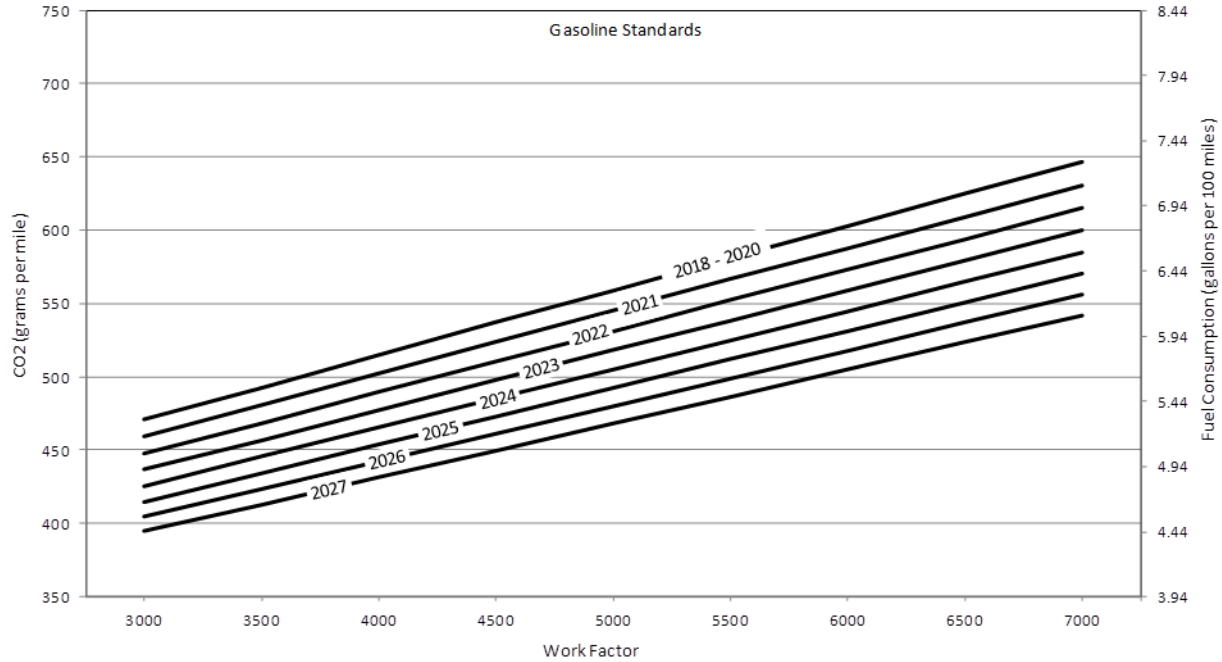


Figure 2.2.5-2. Alternative 3 - Preferred Phase 2 HD Fuel Consumption and CO_2 Standards for Gasoline HD Pickups and Vans



2.3 Direct and Indirect and Cumulative Impacts Analysis Methodologies

CEQ NEPA implementing regulations require agencies to consider the direct and indirect effects and cumulative impacts of major federal actions. CEQ regulations define direct effects as those that "are caused by the action and occur at the same time and place" and indirect effects as those that "are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable." 40 CFR § 1508.8. CEQ regulations define cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions." 40 CFR § 1508.7.

To derive the impacts of the action alternatives reported throughout this document, NHTSA compares the action alternatives to the No Action Alternative. The action alternatives in the direct and indirect impacts analysis and the cumulative impacts analysis are the same, but the No Action Alternative under each analysis reflects different assumptions to distinguish between direct and indirect impacts versus cumulative impacts.

- The analysis of direct and indirect impacts compares action alternatives with a No Action Alternative that generally reflects a small forecast improvement in the average fuel efficiency of new HD vehicles after 2018 due to market-based incentives for improving fuel efficiency. In this way, the analysis of direct and indirect impacts isolates the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the proposed rule, and not attributable to reasonably foreseeable future actions by manufacturers after 2018 to improve new HD vehicle fuel efficiency even in the absence of new regulatory requirements.
- The analysis of cumulative impacts compares action alternatives with a No Action Alternative that generally reflects no forecast improvement in the average fuel efficiency of new HD vehicles after 2018. As a result, the difference between the environmental impacts of the action alternatives and the cumulative impacts baseline reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 (i.e., reasonably foreseeable future changes in HD vehicle fuel efficiency) and the direct and indirect impacts of the Phase 2 standards associated with each action alternative. Therefore, this analysis reflects the cumulative impacts of reasonably foreseeable improvements in fuel efficiency after 2018 due to market-based incentives in addition to the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

The No Action Alternative CO_2 emissions and fuel efficiency standards described in Section 2 reflect the performance levels forecast under the cumulative impacts No Action Alternative. The direct and indirect impacts No Action Alternative reflects a small improvement in the No Action performance levels for tractors shown in Table 2.2.2-1 due to a continuing uptake of technologies in the tractor market that reduce fuel consumption and CO_2 emissions absent Phase 2 regulation. There is no such forecast improvement in vocational vehicle performance after 2017 absent Phase 2 regulation. Therefore, the performance levels for vocational vehicles shown in Tables 2.2.4-1 and 2.2.4-2 would also characterize the direct and indirect impacts No Action Alternative. Market-based improvements in fuel efficiency for HD pickups and vans are expected after 2017, but these improvements are quite small in relation to the annual percentage gains in fuel efficiency for HD pickups and vans under action alternatives shown in Table 2.2.5-1. Therefore, the percentage gains shown in Table 2.2.5-1 are roughly the same in relation to the cumulative impacts No Action Alternative and the direct and indirect No Action Alternative.

2.3.1 Resource Areas Affected and Types of Emissions

The major resource areas affected by the Proposed Action and alternatives are energy, air quality, and climate. Chapter 3 describes the affected environment for energy and energy impacts under each alternative. Chapters 4 and 5 describe the affected environments and impacts for air quality and climate change, respectively.

Emissions, including GHGs, criteria pollutants, and airborne toxics, are categorized for purposes of this analysis as either "downstream" or "upstream." Downstream emissions are released from a vehicle while it is in operation, parked, or being refueled, and consist of tailpipe exhaust, evaporative emissions of volatile compounds from the vehicle's fuel storage and delivery system, and particulates generated by brake and tire wear.[8] Downstream emissions from tractor-trailers and vocational vehicles were estimated using the most recent version of EPA's Motor Vehicle Emission Simulator (MOVES2014) model (EPA 2015). Downstream emissions from Classes 2b–3 vehicles were estimated using the most recent version of NHTSA's CAFE Compliance and Effects Modeling System (the Volpe HD model).

Upstream emissions are those associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels. NHTSA estimated both domestic and international upstream emissions of CO_2, and only domestic upstream emissions of criteria air pollutants and airborne toxics. To estimate Classes 2b–3 upstream emissions changes resulting from decreased downstream fuel consumption, the analysis uses the Volpe HD model, which incorporates emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (2013 version developed by the U.S. Department of Energy Argonne National Laboratory). The Volpe HD model uses the decreased volumes of the fuels along with the emissions factors from GREET for the various fuel production and transport processes to estimate the net changes in upstream emissions as a result of fuel consumption changes. To estimate Classes 4–8 upstream emissions, the analysis uses a spreadsheet model developed by EPA that uses an identical methodology based on GREET emissions factors. Chapters 4 and 5 discuss modeling issues related specifically to the air quality and climate change analyses, respectively.

2.3.1.1 Downstream Emissions

Most downstream emissions are exhaust (tailpipe) emissions. The basic method used to estimate tailpipe emissions entails multiplying the total miles driven by HD vehicles of each model year and age by their estimated emissions rates per vehicle-mile of each pollutant. These emissions rates differ by fuel type (e.g., gasoline and diesel) and by vehicles type and vehicle age.

In calculating emissions, two sets of units can be used depending on how activity levels are measured:

- Activity expressed as vehicle miles traveled (VMT), and emissions factors expressed as grams per VMT
- Activity expressed as fuel consumption in gallons, and emissions factors expressed as grams emitted per gallon of fuel

Considering both sets of units provides insight into how emissions of different GHGs and air pollutants vary with fuel economy and VMT.

[8] NHTSA's authority under EISA does not extend to regulating HFCs, which are released to the atmosphere through air-conditioning system leakage and are not directly related to fuel efficiency.

Almost all of the carbon in fuels that are combusted in vehicle engines is oxidized to CO_2, and essentially all of the sulfur content of the fuel is oxidized to sulfur dioxide (SO_2). As a result, emissions of CO_2 and SO_2 are constant in terms of grams emitted per gallon of fuel; their total emissions vary directly with the total volume of fuel used. Therefore, emissions factors for CO_2 and SO_2 are not constant in terms of grams emitted per VMT of a specific vehicle, because fuel efficiency—and, therefore, the amount of fuel used per VMT—varies with vehicle operating conditions.

In contrast to CO_2 and SO_2, downstream emissions of the other criteria pollutants and the toxic air pollutants are not constant in terms of grams emitted per gallon of fuel. This is because the formation of these pollutants is affected by the continually varying conditions of engine and vehicle operation dictated by the amount of power required, and by the type and efficiency of emissions controls with which a vehicle is equipped.

2.3.1.2 Upstream Emissions

The agencies also estimated the impacts of the action alternatives on upstream emissions associated with petroleum extraction and transportation, and refining, storage, and distribution of transportation fuels. NHTSA and EPA project that the Proposed Action would lead to reductions in upstream emissions from fuel production and distribution, because the total amount of fuel used by HD vehicles would decline under the action alternatives compared to the No Action Alternative.

2.3.2 Energy Market Forecast Assumptions

This EIS uses projections of energy consumption and supply derived from the U.S. Energy Information Administration (EIA), a DOE agency that collects and provides official energy statistics for the United States. EIA is the primary source of data that government agencies and private firms use to analyze and model energy systems. Every year, EIA issues projections of energy consumption and supply for the United States (AEO) and the world (International Energy Outlook [IEO]). EIA reports energy forecasts through 2040 for consumption and supply by energy fuel source, sector, and geographic region. The model used to formulate EIA projections incorporates forecast market trends and all federal and state laws and regulations in force at the time of modeling (e.g., the Phase 1 HD standards and MY 2017–2025 CAFE standards). Potential legislation and laws under debate in Congress are not included. This EIS uses projections of energy consumption and supply based on the 2014 AEO Reference Case. The 2015 AEO was released too recently to be reflected in this analysis; NHTSA will consider whether to incorporate it into the Final EIS.

2.3.3 Modeling Software

The GREET model used to project impacts analyzed in this EIS was last modified by EPA for use in analyzing its 2009 Renewable Fuel Standard 2 (RFS2) proposed rulemaking. In addition, EPA modified the GREET model to add emissions factors for air toxics acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde.

For the action alternatives in this EIS, NHTSA assumed that increased fuel efficiency affects upstream emissions by causing decreases in the volumes of gasoline and diesel produced and consumed. The agencies calculated the impacts of decreased fuel production on total emissions of each pollutant using the volumes of fuels estimated to be produced and consumed under each action alternative, together with emissions factors for individual phases of the fuel production and distribution process derived from GREET. The emissions factors derived from GREET (expressed as grams of pollutant per million British thermal units of fuel energy content) for each phase of the fuel production and distribution process

were multiplied by the volumes of different types of fuel produced and distributed under each action alternative to estimate the resulting changes in emissions during each phase of fuel production and distribution. These emissions were added together to derive the total emissions from fuel production and distribution resulting from each action alternative. This process was repeated for each alternative, and the change in upstream emissions of each pollutant resulting from each action alternative was estimated as the difference between upstream emissions of that pollutant under the action alternative and its upstream emissions under the No Action Alternative. Table 2.3.3-1 lists the software used for computer simulation modeling of the projected HD vehicle fleet and its upstream and downstream emissions for the EIS. The table documents for each software, the common abbreviation, full title, version used, inputs to the software model, and the outputs from the model used in the EIS analysis.

Table 2.3.3-1. Inventory of EIS Modeling Software

Model	Title	Model Inputs	Model Outputs Used in this Analysis
NEMS (AEO 2014)	DOE—National Energy Modeling System	▪ Default values for AEO 2014	▪ Projected fuel prices for all fuels
GREET Fuel-Cycle model, as updated	DOE— GHG and Regulated Emissions in Transportation	▪ Tractor-trailers and vocational vehicles: GREET 1.8c model. In some cases, the GREET values were modified or updated by the agencies to be consistent with the EPA's National Emissions Inventory and emissions factors from MOVES 2014. ▪ Classes 2b–3 vehicles: GREET 2013 model	▪ Estimates of upstream emissions associated with production, transportation, and storage for gasoline, diesel, and E85
MOVES (2014)	EPA—Motor Vehicle Emissions Simulator	▪ Emissions data from in-use chassis testing; remote sensing; state vehicle inspection and maintenance; and other programs	▪ NOx, SOx, CO, VOCs, PM2.5, and toxic emissions factors (tailpipe, evaporative, brake and tire wear) for HD vehicles
Volpe (2015 Version)	Volpe—CAFE Model	▪ Characteristics of baseline vehicle fleet ▪ Availability, applicability, and incremental effectiveness and cost of fuel-saving technologies ▪ Vehicle survival and mileage accumulation patterns ▪ Fuel economy rebound effect ▪ Future fuel prices, social cost of carbon, and other economic factors ▪ Fuel characteristics and criteria pollutant emissions factors	▪ Costs associated with utilization of additional fuel-saving technologies ▪ Changes in travel demand, fuel consumption, fuel outlays, ▪ Technology utilization scenarios ▪ Estimated U.S. vehicle fleet criteria and toxic emissions (tons) for future years

Model	Title	Model Inputs	Model Outputs Used in this Analysis
SMOKE (Version 2.7)	MCNC—Sparse Matrix Operator Kernel Emissions	▪ Criteria pollutant emissions outputs from MOVES, Volpe, or other models ▪ Emissions data for sources other than light-duty vehicles, from EPA National Emissions Inventory	▪ Gridded, speciated, hourly emissions for input into CMAQ and other models
CMAQ (Version 4.7)	EPA—Community Multi-scale Air Quality model	▪ SMOKE outputs ▪ Meteorological data	▪ Estimates of criteria pollutant concentrations and acid deposition. CMAQ includes a meteorological modeling system, emissions models, and a chemistry-transport modeling system for simulation of the chemical transformation and fate
BenMAP-CE (Version 1.1)	EPA—Environmental Benefits Mapping and Analysis Program – Community Edition	▪ CMAQ outputs ▪ Population and population distribution data ▪ Concentration-response data for health outcomes ▪ Valuation data for monetization of health outcomes	▪ Health effects (number of mortality and morbidity outcomes) ▪ Monetized health effects
GCAM RCP Scenario Results	Joint Global Change Research Institute's Global Change Assessment Model's simulations of the Representative Concentration Pathway radiative forcing targets	▪ Regional population estimates ▪ Labor productivity growth ▪ Energy demand ▪ Agriculture, land cover, and land-use models ▪ Atmospheric gas concentrations	▪ GCAMReference, GCAM6.0, and RCP4.5 global GHG emissions scenarios (baselines)
MAGICC (6)	National Center for Atmospheric Research—Model for the Assessment of Greenhouse-gas Induced Climate Change	▪ Adjusted GCAMReference, GCAM6.0, and RCP4.5 climate scenarios to reflect lower projected emissions from the heavy-duty vehicle fleet in the US from the action alternatives	▪ Projected global CO_2 concentrations, and global mean surface temperature, from 2018–2100

Notes:

NEMS = National Energy Modeling System; AEO = Annual Energy Outlook; DOE = U.S. Department of Energy; GREET = Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation; GHG = greenhouse gas; EPA = U.S. Environmental Protection Agency; MOVES = Motor Vehicle Emissions Simulator; E85 = blend of gasoline and ethanol containing 51 to 83 percent ethanol; NO_x = nitrogen oxides; SO_x = sulfur oxides; CO = carbon monoxide; VOCs = volatile organic compounds; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; GCAM = Global Change Assessment Model; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; CO_2 = carbon dioxide; RCP = Representative Concentration Pathway

2.3.4 Approach to Scientific Uncertainty and Incomplete Information

CEQ regulations recognize that many federal agencies encounter limited information and substantial uncertainties when analyzing the potential environmental impacts of their actions. Accordingly, the regulations provide agencies with a means of formally acknowledging incomplete or unavailable information in NEPA documents. Where "information relevant to reasonably foreseeable significant adverse impacts cannot be obtained because the overall costs of obtaining it are exorbitant or the means to obtain it are not known," the regulations require an agency to include in its NEPA document per 40 CFR § 1502.22(b):

1. A statement that such information is incomplete or unavailable
2. A statement of the relevance of the incomplete or unavailable information to evaluating reasonably foreseeable significant adverse impacts on the human environment
3. A summary of existing credible scientific evidence relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment
4. The agency's evaluation of such impacts based on theoretical approaches or research methods generally accepted in the scientific community.

In this EIS, NHTSA uses this approach—acknowledging incomplete or unavailable information—to address areas for which the agency cannot develop a reasonably precise estimate of the potential environmental impacts of the Proposed Action and alternatives. For example, NHTSA recognizes that information about the potential environmental impacts of changes in emissions of CO_2 and other GHGs and associated changes in temperature, including those expected to result from the proposed rule, is incomplete. NHTSA relies on the Intergovernmental Panel on Climate Change (IPCC) 2007 Fifth Assessment Report (IPCC 2013, IPCC 2014) as a recent "summary of existing credible scientific evidence which is relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment." 40 CFR § 1502.22(b)(3).

2.4 Comparison of Alternatives

The CEQ NEPA regulations direct federal agencies to present in an EIS "the environmental impacts of the proposal and the alternatives in comparative form, thus sharply defining the issues and providing a clear basis for choice among options by the decisionmaker and the public."[9] This section summarizes and compares the direct, indirect, and cumulative impacts of the Proposed Action and alternatives on energy resources, air quality, and climate as presented in Chapters 3, 4, and 5. No quantifiable, alternative-specific effects were identified for the other resource areas discussed in Sections 5.5 through 5.6, Chapter 6, and Chapter 7 of this EIS, so they are not summarized here.

In the alternatives analyzed in this EIS, the projected growth in the number of HD vehicles in use throughout the United States and in the annual VMT by HD vehicles would result in increased fuel consumption that outpaces improvements in efficiency resulting from each action alternative over the next decade, but Alternative 3 (Preferred Alternative) and Alternatives 4 and 5 would result in a forecast decline in annual HD vehicle fuel use beginning in the early 2020s. Annual HD vehicle fuel consumption after 2040 would also be lower than in 2015 under the Preferred Alternative and Alternatives 4 and 5. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles. NHTSA estimates that the proposed HD vehicle fuel efficiency

[9] *See* 40 CFR § 1502.14.

standards would reduce fuel consumption and CO_2 emissions from the future levels that would otherwise occur in the absence of the Phase 2 HD Fuel Efficiency Improvement Program (i.e., fuel consumption and CO_2 emissions under the No Action Alternative).

2.4.1 Direct and Indirect Effects

This section compares the direct and indirect effects of the No Action Alternative and the four action alternatives on energy, air quality, and climate as presented in Sections 3.4.1, 4.2.1, and 5.4.1, respectively (s*ee* Table 2.4.1-1). Under NEPA, direct effects "are caused by the action and occur at the same time and place." 40 CFR § 1508.8. Indirect effects are those that "are caused by the action and are later in time or farther removed in distance but are still reasonably foreseeable." 40 CFR § 1508.8.

For detailed discussions of the assumptions and methodologies used to estimate the results presented in this section, *see* Sections 2.3, *Direct and Indirect and Cumulative Impacts Analysis Methodologies*, 3.4.1 (energy), 4.1.2 (air quality), and 5.3 (climate). As explained in Section 2.3, the direct and indirect effects methodology compares the action alternatives with a No Action Alternative that reflects a small forecast increase in the average fuel efficiency of new HD vehicles in 2018 and beyond, due to market-based incentives for improving fuel efficiency. By including these market-based improvements in the No Action Alternative, this analysis attempts to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the proposed rule, and not attributable to reasonably foreseeable future actions by manufacturers.

Table 2.4.1-1. Direct and Indirect Impacts[a]

		Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Energy	Total combined gas, NG, E85, and diesel fuel consumption by all U.S. HD vehicles for 2019–2050	1,971.5 billion DGE	1,852.6 billion DGE	1,744.3 billion DGE	1,733.3 billion DGE	1,661.7 billion DGE
	Total fuel savings by all U.S. HD vehicles compared to No Action Alternative for 2019–2050	--	118.9 billion DGE	227.3 billion DGE	238.2 billion DGE	309.9 billion DGE
Air Quality	Criteria air pollutant emissions reductions from 2018–2050 compared to No Action Alternative	--	Emissions of all criteria pollutants (CO, NO_x, PM2.5, SO_2, and VOCs) will decrease compared to the No Action Alternative. The greatest relative reductions occur for NO_x and VOCs.	Emissions of all criteria pollutants (CO, NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative. The reductions in emissions will be greater than the reductions under Alt. 2 for all criteria pollutants.	Emissions of all criteria pollutants (CO, NO_x, PM2.5, SO_2, and VOCs) will decrease compared to the No Action Alternative. The reductions in emissions will be greater than the reductions under Alt. 3 for all criteria pollutants (except CO in 2018 and 2050).	Emissions of all criteria pollutants (CO, NO_x, PM2.5, SO_2, and VOCs) will decrease compared to the No Action Alternative. The reductions in emissions will be greater than the reductions under Alt. 4 for all criteria pollutants.
	Toxic air pollutants emissions reductions for 2018–2050 compared to No Action Alternative	--	Emissions of all toxic pollutants (acetaldehyde, acrolein, benzene, 1.3-butadiene, DPM, and formaldehyde) will decrease compared to the No Action Alternative in all years except 2018. 1,3-butadiene emissions will	Emissions of all toxic pollutants (acetaldehyde, acrolein, benzene, 1.3-butadiene, DPM, and formaldehyde) will decrease compared to the No Action Alternative in all years except 2018. The decreases in emissions will be similar to those under Alt. 2. 1,3-	Emissions of all toxic pollutants (acetaldehyde, acrolein, benzene, 1.3-butadiene, DPM, and formaldehyde) will decrease compared to the No Action Alternative. All emissions will remain the same or decrease slightly compared to emissions under Alt. 3	Emissions of all toxic pollutants (acetaldehyde, acrolein, benzene, 1.3-butadiene, DPM, and formaldehyde) will decrease compared to the No Action Alternative in all years except 2018. The decreases in emissions will be similar to those under the other action

		Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
			change only slightly in all years.	butadiene emissions will change only slightly in all years.	(except that acetaldehyde and formaldehyde emissions increase slightly in 2050).	alternatives.
Air Quality	Reductions in premature mortality cases and work-loss days in 2035 (values within ranges depend on assumptions used)	--	Premature mortality: reduced by 308 to 707 cases Work-loss days: reduced by 37,464 days	Premature mortality: reduced by 525 to 1,197 cases Work-loss days: reduced by 64,389 days	Premature mortality: reduced by 544 to 1,239 cases Work-loss days: reduced by 66,761 days	Premature mortality: reduced by 692 to 1,573 cases Work-loss days: reduced by 84,927 days
	Range of monetized health benefits in 2035 compared to No Action Alternative under a 3% and 7% discount rate (values within ranges depend on assumptions used)	--	3%: $3,439 million to $7,826 million 7%: $3,088 million to $7,036 million	3%: $5,872 million to $13,281 million 7%: $5,266 million to $11,966 million	3%: $6,085 million to $13,754 million 7%: $5,456 million to $12,395 million	3%: $7,731 million to $17,458 million 7%: $6,931 million to $15,738 million
Climate	Total GHG emissions by all U.S. HD vehicles for 2014–2100	73,600 $MMTCO_2$	68,100 $MMTCO_2$ (5,500 $MMTCO_2$ [7%] less than the No Action Alternative)	62,900 $MMTCO_2$ (10,800 $MMTCO_2$ [15%] less than the No Action Alternative)	62,600 $MMTCO_2$ (11,000 $MMTCO_2$ [15%] less than the No Action Alternative)	59,400 $MMTCO_2$ (14,200 $MMTCO_2$ [19%] less than the No Action Alternative)
	Atmospheric CO_2 concentrations in 2100	789.1 ppm	788.6 ppm (0.5 ppm less than the No Action Alternative)	788.2 ppm in 2100 (0.9 ppm less than the No Action Alternative)	788.2 ppm (0.9 ppm less than the No Action Alternative)	787.9 ppm (1.2 ppm less than the No Action Alternative)
	Increase in global mean surface temperature by 2100	3.484°C	3.483°C (0.002°C less than the No Action Alternative)	3.481°C (0.003°C less than the No Action Alternative)	3.481°C (0.003°C less than the No Action Alternative)	3.480°C by 2100 (0.004°C less than the No Action Alternative)
	Global sea-level rise by 2100	76.28 cm	76.25 cm (0.03 cm less than the No Action Alternative)	76.22 cm (0.06 cm less than the No Action Alternative)	76.22 cm (0.06 cm less than the No Action Alternative)	76.20 cm (0.09 cm less than the No Action Alternative)
	Global mean precipitation increase	5.85%	5.85% (0.00% less than the No	5.85% (0.01% less than the No	5.85% (0.01% less than the No	5.85% (0.01% less than the No

		Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
	by 2100		Action Alternative)	Action Alternative)	Action Alternative)	Action Alternative)

Notes:

[a] The numbers in this table have been rounded for presentation purposes. Therefore, the reductions might not reflect exact difference of the values in all cases.

NG = natural gas; E85 = blend of gasoline and ethanol containing 51 to 83 percent ethanol; DGE = diesel gallons equivalent; CO = carbon monoxide; NO_x = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide; VOCs = volatile organic compounds; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters

2.4.2 Cumulative Impacts

This section compares the cumulative impacts of the No Action Alternative and the four action alternatives on energy, air quality, and climate as presented in Sections 3.4.2, 4.2.2, and 5.4.2, respectively (s*ee* Table 2.4.2-1). CEQ regulations define cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency…or person undertakes such other actions." 40 CFR § 1508.7.

For detailed discussions of the assumptions and methodologies used to estimate the results presented in this Section, *see* Sections 2.3 (Direct and Indirect and Cumulative Impacts Analysis Methodologies), 3.4.2 (energy), 4.1.2 (air quality), and 5.3 (climate). As explained in Section 2.3, the cumulative impacts methodology compares the action alternatives with a No Action Alternative that assumes no increase in the average fuel efficiency of new HD vehicles after 2018 (i.e., no increase beyond the 2014–2018 Phase 1 HD standards). In other words, the difference between the environmental impacts of the action alternatives and the cumulative impacts baseline reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 (i.e., reasonably foreseeable future changes in HD vehicle fuel efficiency) and the direct and indirect impacts of the Phase 2 standards associated with each action alternative.

Table 2.4.2-1. Cumulative Impacts

		Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Energy	Total combined gas, NG, E85, and diesel fuel consumption by all U.S. HD vehicles for 2019–2050	1,991.7 billion DGE	1,852.6 billion DGE	1,744.3 billion DGE	1,733.3 billion DGE	1,661.7 billion DGE
	Total fuel savings by all U.S. HD vehicles compared to No Action Alternative for 2019–2050	--	139.1 billion DGE	247.5 billion DGE	258.4 billion DGE	330.1 billion DGE
Air Quality	Criteria air pollutant emissions reductions for 2018–2050 compared to No Action Alternative	--	Emissions of all criteria pollutant (CO, NO_x, PM2.5, SO_2, and VOCs) will decrease in all years compared to the No Action Alternative.	Emissions of all criteria pollutants (CO, NO_x, PM2.5, SO_2, and VOCs) will decrease in all years compared to the No Action Alternative. The decreases in emissions will be greater than the decreases under Alt. 2.	Emissions of all criteria pollutants (CO, NO_x, PM2.5, SO_2, and VOCs) will decrease in all years compared to the No Action Alternative. The decreases in emissions of all criteria pollutants will be greater than the decreases under Alt. 3 (except for CO in 2018 and 2050).	Emissions of all criteria pollutants (CO, NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease in all years compared to the No Action Alternative. The decreases in emissions of all criteria pollutants will be greater than the decreases under Alt. 4.
	Toxic air pollutants emissions reductions from 2018–2050 compared to No Action Alternative	--	Emissions of all toxic air pollutants (acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde) will decrease in all years compared to the No Action Alternative, except that in 2018 some remain the	Emissions of all toxic air pollutants (acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde) will decrease in all years compared to the No Action Alternative, except that in 2018 some remain the same.	Emissions of all toxic air pollutants (acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde) will decrease in all years compared to the No Action Alternative, except that in 2018 some will remain the	Emissions of all toxic air pollutants (acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde) will decrease in all years compared to the No Action Alternative, except that in 2018 some remain the same. The decreases in emissions will be the same

		Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
			same.	Decreases in all emissions will be greater than under Alt. 2.	same. Decreases in emissions will be the same or slightly greater compared to the decreases under Alt. 3 (except that acetaldehyde and formaldehyde emissions increase slightly in 2050).	or greater compared to the decreases under Alt. 4.
Climate	Reductions in premature mortality cases and work-loss days in 2035 (values within range depend on assumptions used)	--	Premature mortality: reduced by 350 to 801 cases Work-loss days: reduced by 42,728 days	Premature mortality: reduced by 568 to 1,291 cases Work-loss days: reduced by 69,653 days	Premature mortality: reduced by 587 to 1,334 cases Work-loss days: reduced by 72,025 days	Premature mortality: reduced by 734 to 1,667 cases Work-loss days: reduced by 90,191 days
	Range of monetized health benefits in 2035 compared to No Action Alternative under a 3% and 7% discount rate (values within range depend on assumptions used)	--	3%: $3,912 million to $8,879 million 7%: $3,511 million to $7,992 million	3%: $6,345 million to $14,334 million 7%: $5,689 million to $12,921 million	3%: $6,557 million to $14,807 million 7%: $5,879 million to $13,350 million	3%: $8,204million to $18,511 million 7%: $7,354 million to $16,693 million
	Total GHG emissions by All U.S. HD vehicles from 2014–2100	74,700 $MMTCO_2$	68,100 $MMTCO_2$ (6,500 $MMTCO_2$ [9%] less than the No Action Alternative)	62,900 $MMTCO_2$ (11,800 $MMTCO_2$ [16%] less than the No Action Alternative)	62,600 $MMTCO_2$ (12,000 $MMTCO_2$ [16%] less than the No Action Alternative)	59,400 $MMTCO_2$ (15,200 $MMTCO_2$ [20%] less than the No Action Alternative)
	Atmospheric CO_2 concentrations in 2100	687.3 ppm	686.8 ppm (0.5 ppm less than the No Action Alternative)	686.3 ppm (1.0 ppm less than the No Action Alternative)	686.3 ppm (1.0 ppm less than the No Action Alternative)	686.0 ppm (1.3 ppm less than the No Action Alternative)
	Increase in Global Mean Surface Temperature by 2100	2.838°C	2.836°C (0.002 °C less than the No Action Alternative)	2.834°C (0.004 °C less than the No Action Alternative)	2.834°C (0.004°C less than the No Action Alternative)	2.833°C (0.005°C less than the No Action Alternative)

		Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
	Global sea-level rise by 2100	70.22 cm	70.18 cm (0.04 cm less than the No Action Alternative)	70.15 cm (0.07 cm less than the No Action Alternative)	70.15 cm (0.08 cm less than the No Action Alternative)	70.12 cm (0.10 cm less than the No Action Alternative)
	Global mean precipitation increase by 2100	4.77%	4.76% (0.00% less than the No Action Alternative)	4.76% (0.01% less than the No Action Alternative)	4.76% (0.01% less than the No Action Alternative)	4.76% (0.01% less than the No Action Alternative)

Notes:

[a] The numbers in this table have been rounded for presentation purposes. Therefore, the reductions might not reflect exact difference of the values in all cases.

NG = natural gas; E85 = blend of gasoline and ethanol containing 51 to 83 percent ethanol; DGE = diesel gallons equivalent; CO = carbon monoxide; NO_x = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide; VOCs = volatile organic compounds; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters

CHAPTER 3 ENERGY

NHTSA's proposed HD standards would regulate HD fuel efficiency and, therefore, affect U.S. transportation fuel consumption. Transportation fuel comprises a large portion of total U.S. energy consumption and energy imports and has a significant impact on the functioning of the energy sector as a whole. Because transportation fuel consumption will account for most U.S. net energy imports through 2040 (as explained below in this chapter), the United States has the potential to achieve large reductions in imported oil use and, consequently, in net energy imports during this time, by improving the fuel efficiency of HD vehicles. Reducing dependence on energy imports is a key component of President Obama's May 29, 2014, *All-of-the-Above Energy Strategy*, which also states that the development of HD Phase 2 standards "will lead to large savings in fuel, lower CO_2 emissions, and health benefits from reduced particulate matter and ozone" (White House 2014b).

The president's *All-of-the-Above Energy Strategy* documents how the combination of increased U.S. oil and natural gas production, more electricity generation from renewables such as wind and solar, and gains in energy efficiency have produced "substantial economic and energy security benefits." These benefits include a decline in U.S. net petroleum imports, reflecting a decline in crude oil imports, and an increase in refined petroleum product exports, thereby reducing the vulnerability of the United States to foreign oil supply disruptions while also reducing the overall U.S. trade deficit.

This chapter discusses past, present, and forecast U.S. energy production and consumption, and the significant and growing percentage of net energy imports resulting from current HD vehicle fuel consumption trends. This chapter also compares this affected energy environment to energy impacts under the Proposed Action and alternatives. The chapter is organized as follows.

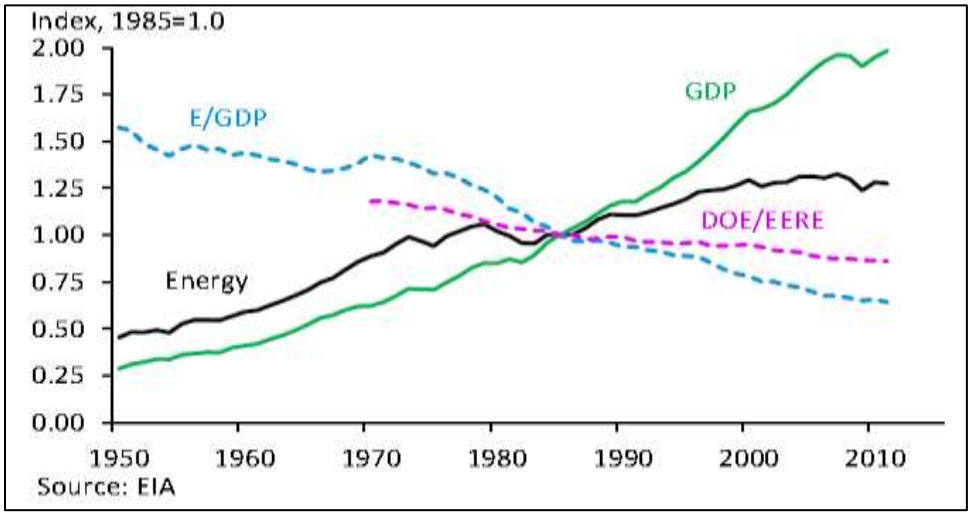
- Section 3.1, *Energy Intensity*, describes energy intensity and consumption and how trends in U.S. energy intensity relate to trends in the U.S. share of global energy consumption.
- Section 3.2, *Affected Environment*, describes the affected environment for U.S. energy production and consumption by primary fuel source (coal, natural gas, petroleum, and other) and consumption sectors (residential, commercial, industrial, and transportation), and how HD vehicle fuel use affects overall energy use.
- Section 3.3, *Heavy-Duty Vehicle Fuel Efficiency and U.S. Energy Security*, describes how improving the fuel efficiency of HD vehicles would affect U.S. energy security by reducing the overall U.S. trade deficit and the macroeconomic vulnerability of the United States to foreign oil supply disruptions.
- Section 3.4, *Environmental Consequences*, describes the energy impacts of the Proposed Action and alternatives, including direct and indirect (Section 3.4.1) and cumulative impacts (Section 3.4.2).

Sections 3.2 and 3.3 provide detailed projections for energy consumption and production through 2040, from the *Annual Energy Outlook* (AEO) 2014 (AEO 2015 was released too recently to be reflected in this analysis, but will be considered in the Final EIS), including data reported in *All-of-the-Above Energy Strategy*, from the AEO 2014 (EIA 2014a). These forecasts reflect current enacted legislation and final regulations as of the end of October 2013, but do not reflect the impacts of the Proposed Action, which are discussed in Section 3.4.

3.1 Energy Intensity

Energy intensity is often calculated as the sum of all energy supplied to an economy (in thousand British thermal units [Btu]) divided by its real (inflation-adjusted) gross domestic product (GDP; the combined market price of all the goods and services produced in an economy at a given time). This energy-GDP ratio (E/GDP) can decline due to improvements in energy efficiency and/or shifts from more to less energy-intensive sectors of the economy (e.g., an increasing percentage of GDP from the services sector and a decrease in the percentage of GDP from energy-intensive manufacturing). The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) has developed an economy-wide energy intensity index that estimates how the amount of energy needed to produce the same basket of goods has changed over time. Figure 3.1-1 shows that this DOE/EERE index fell by 14 percent from 1985 to 2011, as the E/GDP ratio fell by 36 percent, illustrating that the decline in energy use per dollar of GDP has come from improvements in energy efficiency and shifts in the composition of GDP.

Figure 3.1-1. U.S. Energy Intensity, 1950–2011



Source: White House 2014b.

Figure 3.1-1 also shows that the relationship between growth in GDP and total energy consumption has changed over the past 6 decades. From 1950 to 1970, GDP growth was associated with nearly parallel growth in energy consumption, with little change in energy intensity. From 1970 to 2000, the DOE/EERE and E/GDP measures of energy intensity both declined, but total energy consumption still increased as GDP growth more than offset improvements in energy efficiency and shifts in GDP composition that reduced energy intensity. From 2000 to 2011, the United States recorded substantial GDP growth with almost no increase in energy consumption due to reductions in energy intensity. The AEO forecasts ongoing declines in U.S. energy intensity, with average 2012–2040 GDP growth of 2.4 percent per year resulting in average annual total energy consumption growth of just 0.4 percent (EIA 2014a).

The decline in U.S. energy intensity, combined with rapid economic growth and increased energy use in many developing nations, has significantly reduced the U.S. share of international energy consumption. In 1980, the United States accounted for 27.6 percent of world energy consumption. By 2009, the U.S. share had fallen to 19.4 percent (EIA 2014b), and the 2014 International Energy Outlook forecasts that the U.S. share of global energy consumption will fall to 13.1 percent by 2040 (EIA 2014c).

3.2 Affected Environment

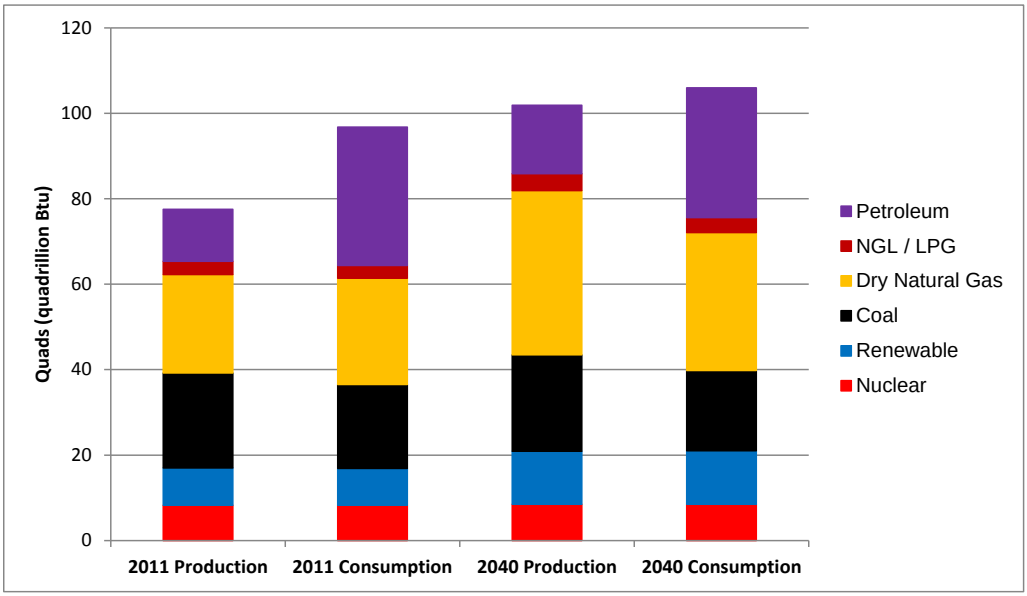
Although petroleum is overwhelmingly the primary source of energy for HD vehicles today, HD vehicles can use other fuels (e.g., natural gas), and the Proposed Action has the potential to reduce transportation petroleum demand and thereby affect the availability and use of fuels consumed by different economic sectors. Understanding how primary fuel markets are expected to evolve in the coming years also provides context for considering energy impacts of the Proposed Action. Therefore, the affected environment for energy encompasses current and projected U.S. energy consumption and production across all fuels and sectors. Section 3.2.1 discusses U.S. energy production and consumption by primary fuel source (petroleum, coal, natural gas, and other). Section 3.2.2 discusses U.S. energy consumption by sector.

3.2.1 U.S. Production and Consumption of Primary Fuels

Primary fuels are energy sources consumed in the initial production of energy. Energy sources used in the United States include nuclear power, coal, natural gas, crude oil (converted to petroleum products for consumption), and natural gas liquids (converted to liquefied petroleum gases for consumption). These five energy sources accounted for 91 percent of U.S. energy consumption in 2011. Hydropower, biomass, solar, wind, and other renewable energy accounted for 9 percent of U.S. energy consumption in 2011.

By 2040, the top five aforementioned energy sources are forecast to account for 88 percent of U.S. energy consumption, a reduction of 3 percent from their previous share, while the share of energy from renewable fuels is forecast to rise to 12 percent (EIA 2014a). Forecast gains in U.S. oil and natural gas production, more electricity generation from renewables, and energy efficiency improvements are expected to significantly reduce the difference between U.S. energy production and consumption by 2040, thereby reducing U.S. reliance on energy imports. Figure 3.2.1-1 illustrates this change in U.S. fuel consumption and production from 2011 to 2040 (not including the impacts of the Proposed Action).

Figure 3.2.1-1. U.S. Energy Production and Consumption by Source in 2011 and 2040



Source: EIA 2014a

From 2011 to 2040, production and consumption of nuclear power is forecast to increase from 8.3 to 8.5 quadrillion Btu (quads), and production and consumption of renewable fuel is forecast to increase from approximately 8.7 quads in 2011 to 12.5 quads in 2040. The forecast growth in renewable energy includes a decline in hydropower production and consumption from 3.1 quads in 2011 to 2.9 quads in 2040, and increases in biomass energy (e.g., ethanol and other liquid fuel from crops, and grid-connected electricity from wood and other biomass) and other renewable energy (e.g., wind and solar), from approximately 5.6 quads in 2011 to 9.6 quads in 2040. Electric power generation accounts for two-thirds of the forecast growth in renewable fuel use, and the industrial sector accounts for another 28 percent. Because production and consumption are roughly equivalent for nuclear and renewable energy, there are essentially no net imports associated with these energy sources.[1] These fuels supplied 17.4 percent of U.S. energy consumption in 2011, and their share of consumption is forecast to increase to 19.8 percent by 2040.

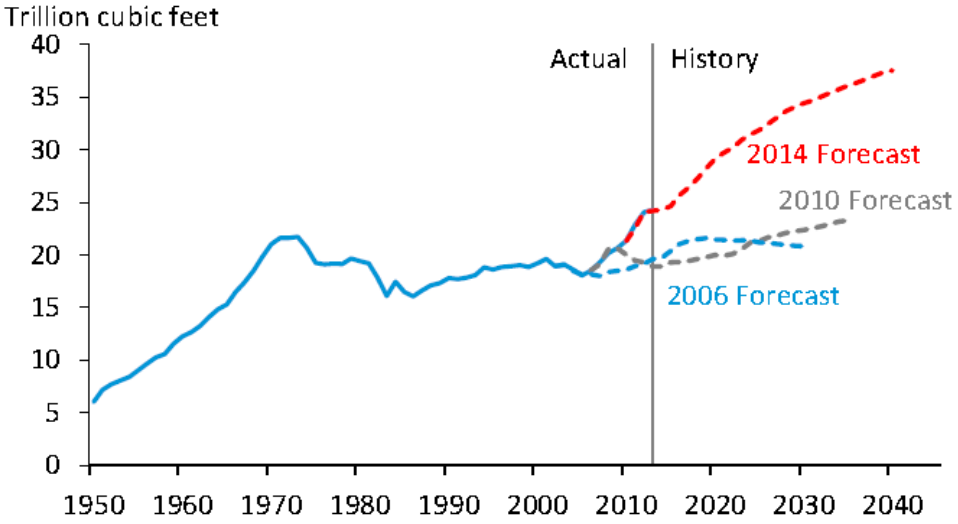
U.S. coal production is forecast to increase from 22.2 quads in 2011 to 22.6 quads in 2040, as coal consumption is expected to decline from 19.6 quads in 2011 to 18.7 quads in 2040. The United States is currently, and is expected to remain, a net exporter of coal energy through 2040, because the country is expected to continue to produce more coal than it consumes.

U.S. production of dry natural gas (separated from natural gas liquids, discussed below) is forecast to increase from 23.0 quads in 2009 to 38.4 quads in 2040, while consumption of natural gas is expected to rise from 24.9 quads in 2011 to 32.3 quads in 2040, making the United States a net exporter of dry natural gas in 2017 through 2040. The forecast growth in natural gas is due to new production technologies that have enabled an 11-fold increase in U.S. shale gas production from 2005 to 2011, with another 250 percent increase forecast for 2011 to 2040, more than offsetting declines in conventional natural gas production. The surge in shale gas production is why the AEO 2014 (EIA 2014a) forecast anticipates much higher natural gas production than had been foreseen in the AEO 2006 and 2010 forecasts (EIA 2006, 2010), as shown in Figure 3.2.1-2.

Production of natural gas liquid (NGL, a similar but heavier hydrocarbon compared to dry natural gas) is forecast to increase from 3.1 quads in 2011 to 4.0 quads in 2040. After extraction, natural gas liquid is separated from dry natural gas in processing plants and sold as ethane, propane, and other liquefied petroleum gases. Liquefied petroleum gas (LPG) consumption is forecast to increase from 3.0 quads in 2011 to 3.5 quads in 2040. Therefore, the increase in NGL production is expected to outpace the growth in LPG consumption, resulting in net exports for this subset of liquid fuels in 2011 through 2040. U.S. production of crude oil is forecast to increase from 12.2 quads in 2011 to 16.0 quads in 2040. Crude oil is refined into petroleum products (including gasoline and diesel, but excluding non-petroleum liquid fuels, such as biofuels and LPG).

[1] There are virtually no U.S. net imports of nuclear power in the sense that U.S. consumption of electricity generated by nuclear power is supplied by U.S. nuclear power plants. Supply and consumption of nuclear fuel at different stages of processing is more complex, encompassing a nuclear fuel cycle that includes mining of uranium ore, conversion into uranium hexafluoride, and enrichment to increase the concentration of uranium-235 in uranium hexafluoride. U.S. nuclear plants in 2012 purchased 83 percent of their total uranium consumption from foreign suppliers, and 38 percent of the enriched uranium needed to fabricate fuel for U.S. reactors was supplied by foreign enrichers (EIA 2013).

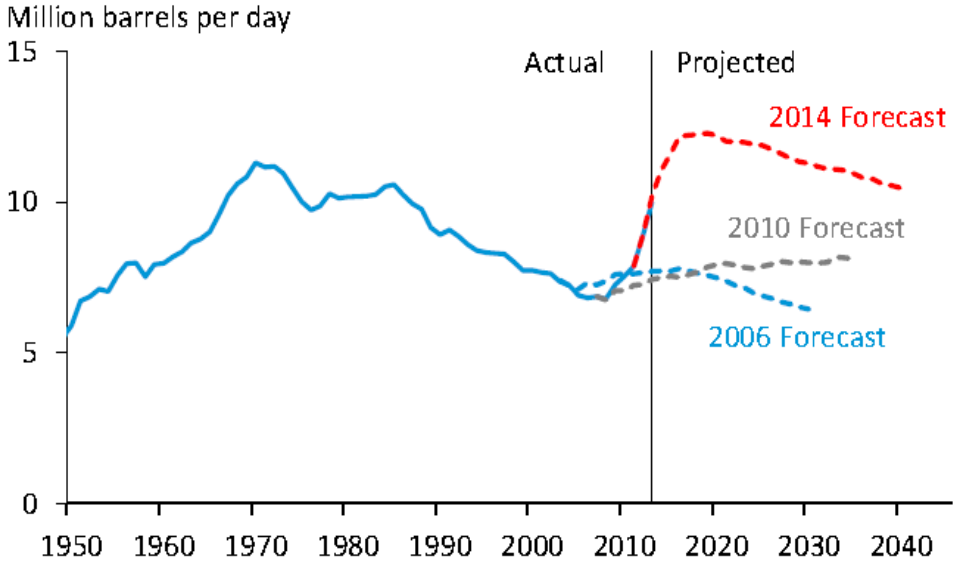
Figure 3.2.1-2. U.S. Natural Gas Production, 1950–2040



Source: White House 2014b.

U.S. consumption of petroleum is forecast to decline from 32.4 quads in 2011 to 30.4 quads in 2040. Therefore, U.S. net imports of petroleum are forecast to decline from approximately 20 quads (3,602 million barrels) in 2011 to 14 quads (2,522 million barrels) in 2040. As in the case of natural gas production, advances in oil drilling technology have resulted in a higher AEO 2014 (EIA 2014a) forecast for U.S. crude oil production than had been foreseen in the AEO 2006 and 2010 (EIA 2006, 2010) forecasts, as shown in Figure 3.2.1-3.

Figure 3.2.1-3. U.S. Petroleum Production, 1950–2040



Source: White House 2014b.

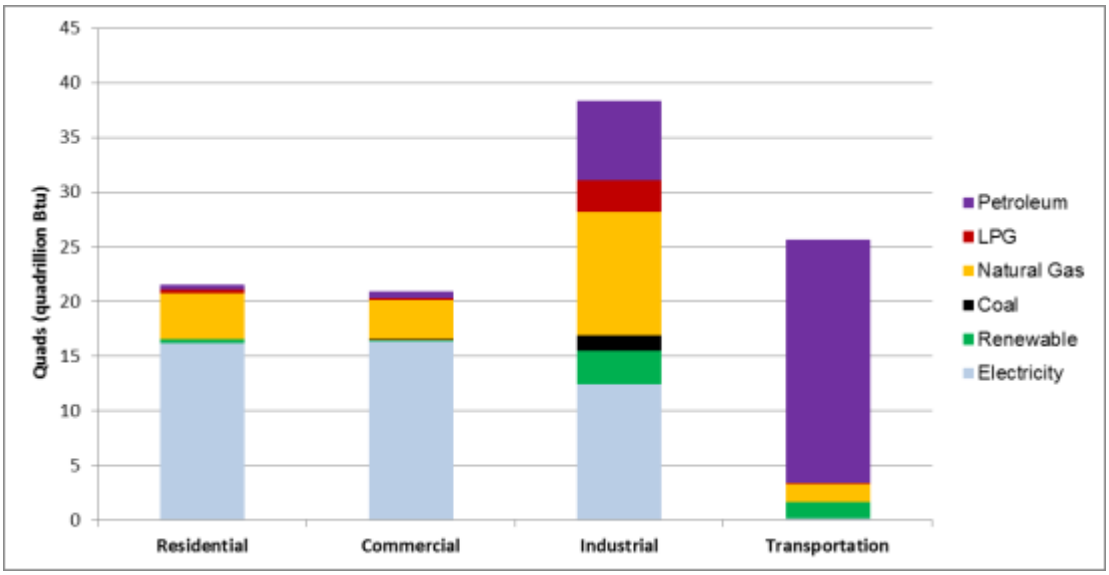
The primary fuel projections discussed above demonstrate that there are likely to be essentially no U.S. net imports of nuclear power and renewable energy, with U.S. net exports expected for coal, natural gas, and NGL from 2017 through 2040. Despite forecast reductions in petroleum net imports, U.S. petroleum net imports are still expected to exceed the net exports of other primary fuels, resulting in a continued U.S. reliance on net energy imports through 2040. As stated above, these forecasts do not include impacts from the Proposed Action, which would contribute to additional declines in petroleum consumption (discussed in Section 3.4) and associated reductions in petroleum net imports.

3.2.2 U.S. Energy Consumption by Sector

While Section 3.2.1 describes overall U.S. production and consumption of primary fuels, this section discusses the usage of primary fuels by sector. Energy consumption occurs in four broad economic sectors: industrial, residential, commercial, and transportation. These sectors can be categorized as stationary (including industrial, residential, and commercial sectors) or mobile (i.e., transportation). Stationary and transportation sectors consume the primary fuels described above (e.g., nuclear, coal, and petroleum) and electricity. Electric power generation consumes primary fuel to provide electricity to the industrial, residential, commercial, and transportation sectors. Total primary energy consumption for electric power generation is forecast to increase from 39.1 quads in 2011 to 44.9 quads in 2040. In 2011, nuclear power supplied 21 percent of electric power generation source fuel, coal 46 percent, natural gas 20 percent, and renewable energy 12 percent. In 2040, nuclear power is expected to supply 19 percent of electric power generation source fuel, coal 38 percent, natural gas 26 percent, and renewable energy 17 percent. The petroleum share of electric power fuel supply is anticipated to decline from 1.0 percent in 2009 to just 0.4 percent in 2040.

Figure 3.2.2-1 illustrates sharply contrasting profiles for 2040 fuel consumption forecasts for stationary and transportation sectors, with stationary sectors consuming more electricity and natural gas, and the transportation sector consuming primarily petroleum. Sections 3.2.2.1 and 3.2.2.2 discuss the specifics of fuel use by stationary and transportation sectors, respectively.

Figure 3.2.2-1. Forecast U.S. Energy Consumption by End-Use Sector and Source Fuel in 2040



Source: EIA 2014a

3.2.2.1 Stationary-Sector Fuel Consumption

This section provides background information on stationary-sector fuel consumption, on which the Proposed Action would have a relatively small impact. Section 3.2.2.2 discusses transportation fuel consumption, on which the Proposed Action would be expected to have a larger impact.

Electricity (including energy losses during generation and transmission) and natural gas used on site (for heat, cooking, and hot water) are the principal forms of energy used by the residential and commercial sectors, accounting for 94 percent of 2011 energy use and 95 percent of forecast 2040 energy use in these two sectors. The industrial sector has more diverse energy consumption patterns, including coal, LPG, petroleum, and renewable energy, but electricity and natural gas still accounted for 57 percent of 2011 industrial sector energy use, and account for 62 percent of forecast 2040 energy use in this sector. New energy technologies to supply stationary energy to consumers must compete with an existing infrastructure that delivers electricity and natural gas reliably and at a relatively low cost, but energy efficiency improvements are expected to restrain total energy consumption growth in these sectors.

Residential-sector energy consumption is forecast to be little changed at 21.4 quads in 2011 and 21.5 quads in 2040, with this sector accounting for 22 percent of total U.S. energy consumption in 2011 and 20 percent of total forecast U.S. energy consumption in 2040. Residential consumption of liquid fuel (propane, kerosene, and distillate fuel oil) is expected to fall from 1.1 quads in 2011 to 0.7 quads in 2040. Residential renewable fuel use (primarily wood for heating) is expected to decline from 0.5 quads in 2011 to 0.4 quads in 2040. Residential natural gas use is forecast to fall from 4.8 quads in 2011 to 4.2 quads in 2040, as residential electricity use increases from 15.0 quads in 2011 to 16.2 quads in 2040.

Commercial-sector energy consumption is forecast to rise from 18.1 quads in 2011 to 20.9 quads in 2040, with this sector accounting for 19 percent of total U.S. energy consumption in 2011 and 20 percent of total forecast U.S. energy consumption in 2040. Commercial consumption of liquid fuel, renewable energy, and coal are all expected to be essentially the same in 2011 and 2040, at 0.7 quads for liquid fuel, 0.1 quads for renewable energy, and 0.05 quads for coal. Commercial natural gas use is expected to increase from 3.2 quads in 2011 to 3.6 quads in 2040, and commercial electricity use is forecast to increase from 14.0 quads in 2011 to 16.4 quads in 2040.

Industrial-sector energy consumption is projected to rise from 30.5 quads in 2011 to 38.3 quads in 2040, with this sector accounting for 31 percent of total U.S. energy consumption in 2011 and 36 percent of total forecast U.S. energy consumption in 2040. Industrial-sector consumption of LPG is expected to increase from 2.2 quads in 2011 to 2.9 quads in 2040, petrochemical feedstock consumption is forecast to increase from 0.9 quads in 2011 to 1.6 quads in 2040, and other petroleum product liquid fuel use is expected to increase from 5.0 quads in 2011 to 5.6 quads in 2040. Industrial coal use is expected to decline from 1.5 quads in 2011 to 1.4 quads in 2040. Industrial consumption of renewable energy is expected to increase from 2.0 quads in 2011 to 3.1 quads in 2040, electricity use is forecast to increase from 10.4 quads in 2011 to 12.4 quads in 2040, and natural gas consumption is forecast to increase from 8.4 quads in 2011 to 11.3 quads in 2040.

3.2.2.2 Transportation-Sector Fuel Consumption

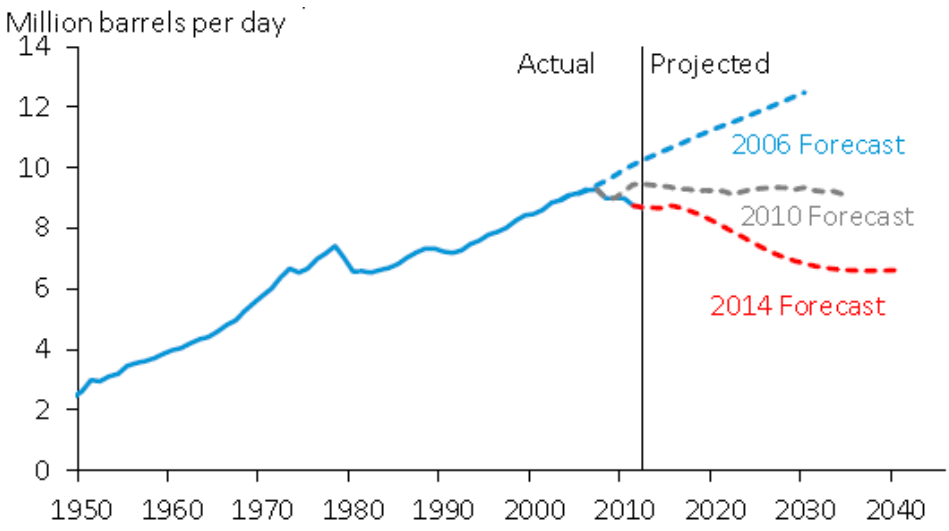
Transportation-sector fuel consumption is forecast to decline from 27.2 quads in 2011 to 25.6 quads in 2040. In 2011, petroleum supplied 92.4 percent of transportation energy demand, biofuel (mostly ethanol used in gasoline blending) supplied 4.4 percent, natural gas 2.7 percent, electricity 0.3 percent, and LPG (propane) 0.2 percent. In 2040, petroleum is expected to supply 86.6 percent of transportation energy demand, biofuel 5.8 percent, natural gas 6.7 percent, electricity 0.7 percent, and LPG 0.3 percent.

In 2011, light-duty vehicles (cars and light trucks) accounted for 57 percent of transportation energy consumption, HD vehicles accounted for 22 percent, air travel accounted for 9 percent, and other transportation (e.g., boats, rail, pipeline) accounted for 12 percent. In 2040, light-duty vehicles are expected to account for 45 percent of transportation energy consumption, HD vehicles 32 percent, air travel 11 percent, and other transportation 12 percent. The HD vehicle percentage of total transportation energy consumption is projected to increase due to an increase in HD vehicle fuel consumption and a decrease in light-duty vehicle gasoline consumption, as discussed below.

In 2011, the transportation sector accounted for 77.6 percent of total U.S. petroleum consumption. In 2040, transportation is expected to account for 73 percent of total U.S. petroleum consumption, with the industrial sector accounting for 23.7 percent. The residential and commercial sectors and electricity generation combined are expected to account for just 3.3 percent of U.S. petroleum consumption in 2040. With petroleum expected to account for all U.S. net energy imports in 2040, and transportation expected to account for 73 percent of total petroleum consumption in 2040, U.S. net energy imports in 2040 are expected to result primarily from fuel consumption by light-duty and HD vehicles.

The forecast decline in transportation-sector energy consumption is led by a forecast decline in gasoline use that reflects fuel economy and fuel efficiency improvements stemming from the model year (MY) 2012–2016 and MY 2017–2025 CAFE standards Final EIS and to a lesser extent, the Phase 1 HD standards. Improvements in fuel efficiency, combined with a slower AEO 2014 (EIA 2014a) forecast growth rate for vehicle miles traveled, are why the AEO 2014 forecasts much lower gasoline consumption than had been projected in the AEO 2006 and 2010 forecasts (EIA 2006, 2010), as shown in Figure 3.2.2-2.

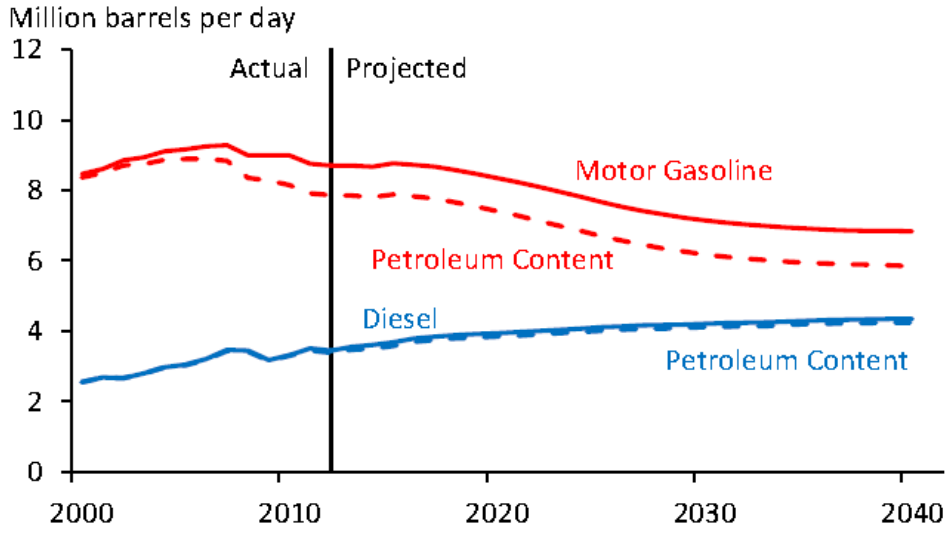
Figure 3.2.2-2. U.S. Consumption of Motor Gasoline, 1950–2040



Source: White House 2014b.

The forecast amount of petroleum consumed in gasoline is also reduced by ethanol blending in gasoline. As recently as 2000, U.S. gasoline consumption was almost entirely associated with petroleum content, but ethanol is now blended into nearly all U.S. gasoline as E10, which is 10 percent ethanol by volume, thereby reducing the petroleum content of gasoline, as shown in Figure 3.2.2-3. This figure also shows that the forecast decline in motor gasoline consumption through 2040 is expected to be partially offset by an increase in diesel fuel consumption, with forecast diesel consumption almost entirely associated with petroleum content (reflecting a relatively small forecast amount of biodiesel consumption). As noted above, this forecast does not reflect impacts of the Proposed Action.

Figure 3.2.2-3. U.S. Motor Gasoline and Diesel Fuel Consumption, 2000–2040



Source: White House 2014b.

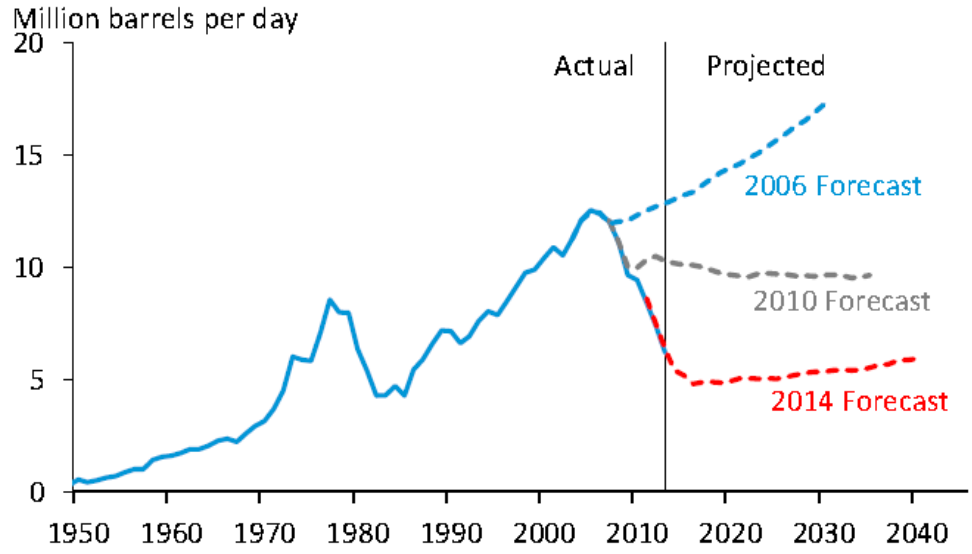
In 2011, gasoline accounted for 99.4 percent of light-duty vehicle fuel consumption and diesel accounted for 0.3 percent. In 2040, gasoline is expected to account for 93.2 percent of light-duty vehicle fuel and diesel is expected to account for 3.2 percent. By contrast, gasoline accounted for 12.6 percent of 2011 HD vehicle fuel consumption and diesel accounted for 86.7 percent. In 2040, gasoline is expected to account for 9.4 percent of HD vehicle fuel and diesel is expected to account for 81.7 percent. The share of HD vehicle fuel supplied by compressed natural gas (CNG) and liquefied natural gas (LNG) is expected to increase from 0.4 percent in 2011 to 8.6 percent in 2040. As noted above, this vehicle fuel forecast does not reflect the potential impacts of the Proposed Action.

3.3 HD Vehicle Fuel Efficiency and U.S. Energy Security

Section 3.2 shows that the United States is expected to have net energy exports in 2017 through 2040 for the combination of all source fuels except for petroleum. In 2040, transportation is expected to account for 73 percent of total U.S. petroleum consumption, with light-duty vehicles accounting for 45 percent of transportation energy consumption, and HD vehicles accounting for 32 percent. A forecast decline in transportation energy consumption is led by a forecast decline in gasoline use that primarily reflects the impacts of MY 2012–2016 and MY 2017–2025 light-duty CAFE standards, with gasoline expected to account for 93.2 percent of light-duty vehicle energy consumption in 2040. This forecast decline in gasoline consumption is expected to be partially offset by a forecast increase in diesel fuel consumption, with diesel expected to account for 81.7 percent of HD vehicle fuel in 2040 (this diesel forecast does not reflect impacts of the Proposed Action). Therefore, the proposed Phase 2 standards for HD vehicle fuel efficiency target the segment of the affected environment for energy where there is significant potential to further reduce net petroleum imports and overall net energy imports.

As shown in Figure 3.3-1, U.S. net petroleum imports have fallen from a peak of over 12 million barrels per day (bpd) in 2005 to 6.2 million bpd in 2013. The president's *All-of-the-Above Energy Strategy* notes that roughly 35 percent of this steep decline in net petroleum imports is due to increases in U.S. production, and 65 percent is due to reductions in U.S. petroleum consumption (White House 2014b).

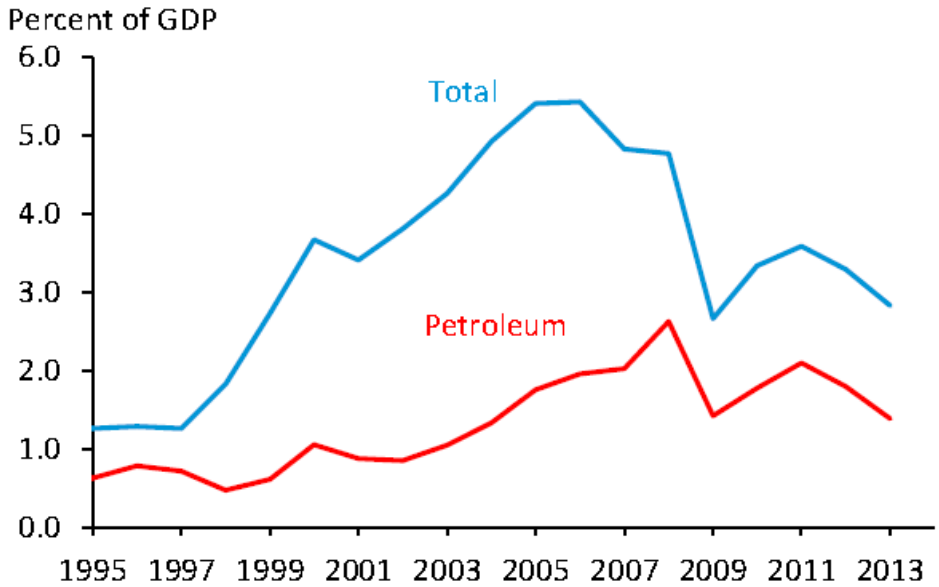
Figure 3.3-1. U.S. Petroleum Net Imports, 1950–2040



Source: White House 2014b.

The president's *All-of-the-Above Energy Strategy* also notes that the drop in net petroleum imports has accounted for more than 20 percent of a substantial decline in the U.S. trade deficit over recent years (White House 2014b), as shown in Figure 3.3-2. The total U.S. trade balance fell from 5.4 percent of GDP in 2006 (the highest recorded for the United States) to 2.8 percent by the end of 2013 (the lowest since 1999, excluding the financial crisis-affected year of 2009).

Figure 3.3-2. Total and Petroleum Trade Deficits, 1995–2013

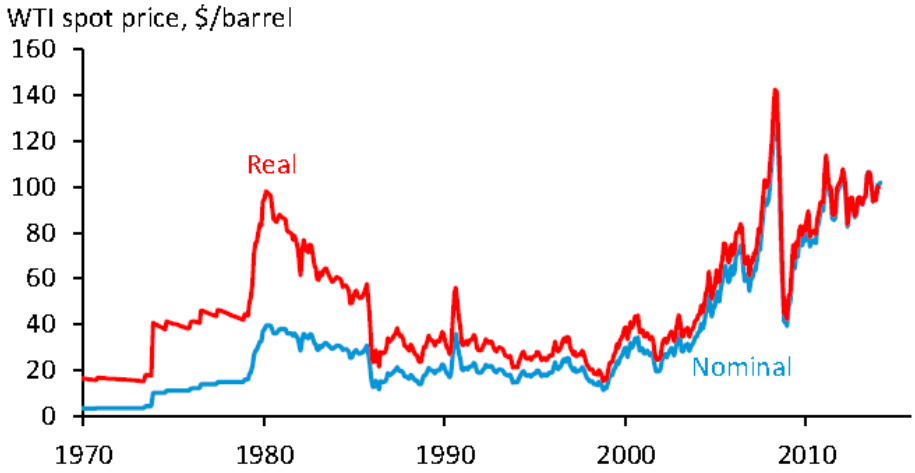


Source: White House 2014b.

The impact of net petroleum imports on the U.S. trade deficit reflects both the physical volume of net imports (in bpd, as shown in Figure 3.3-1) and the prevailing price of crude oil that determines the dollar value of any given volume of net petroleum imports.

Figure 3.3-3 shows that real (inflation-adjusted) spot prices for West Texas Intermediate (WTI) crude oil have been near $100 per barrel in recent years, which is comparable with peak oil prices in the late 1970s and early 1980s, and roughly three times the real price of crude oil in the 1990s. The WTI benchmark price has a significant impact on petroleum product prices including the price of motor gasoline and diesel.

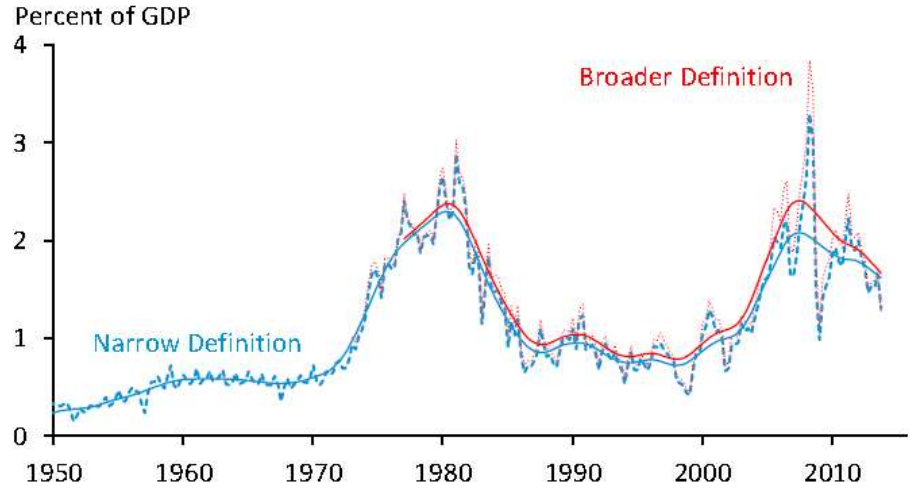
Figure 3.3-3. Nominal and Real Oil Prices (2013 $)



Source: White House 2014b.
WTI = West Texas Intermediate

During the 1990s, net petroleum physical imports were high but the cost of net imports as a percentage of GDP was relatively low because the real price of oil was relatively low. In recent years, high oil prices have increased the cost of net imports as a percentage of GDP even as net petroleum physical imports have declined due to increasing domestic oil production, substituting biofuels and other fuels for petroleum use, and improving the energy efficiency of petroleum product consumption. Figure 3.3-4 shows that the trend in net petroleum imports as a percentage of GDP has followed a pattern since 1970 that is closely related to the trend in real oil prices (shown above in Figure 3.3-3).

Figure 3.3-4. Net Import Shares of Petroleum Products[2]



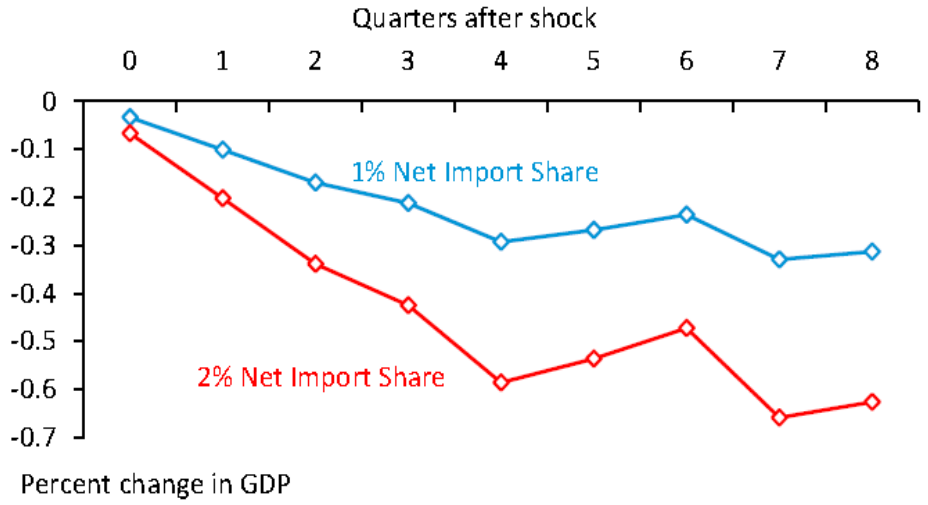
Source: White House 2014b.
GDP = gross domestic product

[2] The narrow measure of net imports in the figure includes net imports of crude, gasoline, distillates, and fuel oil; the broader measure, available since 1973, includes naphtha, jet fuel, and other refined products, which slightly increases the net import share relative to the narrow measure but does not materially change the trend pattern.

The United States cannot control the global price of crude oil, which is determined by global supply and demand for oil; however, the United States can further reduce the net petroleum trade deficit by further reducing the physical volume of net petroleum imports. In addition to reducing the U.S. trade deficit, the president's *All-of-the-Above Energy Strategy* (White House 2014b) also presents an analysis of macroeconomic energy security benefits of reducing net petroleum imports associated with making the U.S. economy less vulnerable to oil price shocks arising from foreign supply disruptions. This analysis highlights a number of supply disruptions that have occurred since 1970. These disruptions resulted in rapid oil price increases of 28 to 53 percent that cut GDP growth and reduced employment over several quarters.

The analysis shows that the negative impact on GDP growth is moderated when U.S. net petroleum imports account for a smaller percent of GDP: if a 10 percent increase in oil prices occurs when net petroleum imports account for 2 percent of GDP, then the negative cumulative impact on GDP growth over subsequent quarters is about twice as severe as the same 10 percent increase in oil prices would be if net petroleum imports accounted for 1 percent of GDP, as shown in Figure 3.3-5.

Figure 3.3-5. Estimated Cumulative Effect of a 10 Percent Oil Price Shock on GDP



Source: White House 2014b.
GDP = gross domestic product

3.4 Environmental Consequences

Section 3.4.1 examines direct and indirect impacts on fuel consumption associated with each of the action alternatives. Section 3.4.2 examines cumulative fuel consumption impacts. Section 3.4.3 also shows how the action alternatives would alter the affected energy environment described above in Section 3.2.

3.4.1 Direct and Indirect Impacts

Table 3.4.1-1 shows the direct and indirect impacts on total fuel consumption by the entire HD fleet for calendar years 2019 through 2050 from each alternative, including Alternative 1 (No Action Alternative). This analysis assumes a small forecast improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond under the No Action Alternative, due to market-based incentives for improving fuel efficiency.[3] Table 3.4.1-1 also shows the direct and indirect fuel savings for each action alternative, compared to the No Action Alternative, through 2050, when almost the entire HD vehicle fleet is likely to be composed of vehicles subject to Phase 2 standards.

Table 3.4.1-1. Direct and Indirect HD Vehicle Fuel Consumption and Fuel Savings by Alternative, 2019–2050

	Billion Diesel Gallon Equivalents				
	Alt. 1 - No Action	Alt. 2	Alt. 3 - Preferred	Alt. 4	Alt. 5
Fuel Consumption					
HD Pickups and Vans	284.7	272.4	261.5	258.5	254.9
Vocational Vehicles	398.8	390.3	367.8	365.4	348.7
Tractor Trucks and Trailers	1,288.0	1,190.0	1,114.9	1,109.4	1,058.1
All HD Vehicles	1,971.5	1,852.6	1,744.3	1,733.3	1,661.7
Fuel Savings Compared to Alt. 1 – No Action					
HD Pickups and Vans	--	12.3	23.2	26.2	29.8
Vocational Vehicles	--	8.6	31.0	33.5	50.2
Tractor Trucks and Trailers	--	98.0	173.1	178.5	229.9
All HD Vehicles	--	118.9	227.3	238.2	309.9

This table reports total 2019–2050 fuel consumption in diesel gallon equivalents (DGE) for diesel, gasoline, natural gas (NG), and E85 fuel, for HD pickups and vans (Classes 2b–3), vocational vehicles (Classes 2b–8), and tractor-trailers (Classes 7–8), for each alternative. Gasoline accounts for approximately 55 percent of HD pickup and van fuel use, 22 percent of vocational vehicle fuel use, and just 0.0001 percent of tractor-trailer fuel use. E85 accounts for less than 0.4 percent of HD pickup and van fuel use, NG accounts for less than 1 percent of vocational vehicle fuel use, and E85 and NG use are expected to be negligible for other vehicle categories. Diesel accounts for approximately 45 percent of HD pickup and van fuel use, 77 percent of vocational vehicle fuel use, and 100 percent of tractor trailer fuel use.

[3] As explained in Chapter 2, the analysis of direct and indirect impacts compares the action alternatives with a No Action Alternative that assumes market-based improvements in order to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the proposed rule, and not attributable to reasonably foreseeable future actions by manufacturers.

Assuming the small forecast improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative is projected to be 1971.5 billion DGE. Total projected 2019–2050 fuel consumption decreases across the action alternatives, from 1852.6 billion DGE under Alternative 2 to 1661.7 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 direct and indirect fuel savings ranging from 118.9 billion DGE under Alternative 2 to 309.9 billion DGE under Alternative 5. Under Alternative 3 (Preferred Alternative), total projected fuel consumption from 2019–2050 would be 1744.3 billion DGE, and direct and indirect fuel savings compared to the No Action Alternative would be 227.3 billion DGE.

3.4.2 Cumulative Impacts

Table 3.4.2-1 shows the cumulative impacts on total fuel consumption by the entire HD fleet for calendar years 2019 through 2050 from each alternative, including the No Action Alternative. It also shows the cumulative fuel savings for each action alternative, compared to the No Action Alternative, through 2050. Total 2019–2050 fuel consumption for each action alternative in this table is the same as shown for the corresponding action alternative in Table 3.4.1-1.

Table 3.4.2-1. Cumulative HD Vehicle Fuel Consumption and Fuel Savings by Alternative, 2014–2050

	Billion Diesel Gallon Equivalents				
	Alt. 1 - No Action	Alt. 2	Alt. 3 - Preferred	Alt. 4	Alt. 5
Fuel Consumption					
HD Pickups and Vans	288.0	272.4	261.5	258.5	254.9
Vocational Vehicles	398.8	390.3	367.8	365.4	348.7
Tractor Trucks and Trailers	1,304.9	1,190.0	1,114.9	1,109.4	1,058.1
All HD Vehicles	1,991.7	1,852.6	1,744.3	1,733.3	1,661.7
Fuel Savings Compared to Alt. 1 - No Action					
HD Pickups and Vans	--	15.6	26.5	29.5	33.1
Vocational Vehicles	--	8.6	31.0	33.5	50.2
Tractor Trucks and Trailers	--	114.9	190.0	195.4	246.8
All HD Trucks	--	139.1	247.5	258.4	330.1

The No Action Alternative fuel consumption is higher in Table 3.4.2-1 than in Table 3.4.1-1 because the No Action fuel consumption numbers below do not reflect any forecast improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond. As a result, the fuel savings estimates below reflect the cumulative impact of reasonably foreseeable improvements in fuel efficiency after 2018 due to market-based incentives in addition to the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

Assuming no improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative is projected to amount to 1991.7 billion DGE. Total projected 2019–2050 fuel consumption decreases across the action alternatives to levels ranging from 1852.6 billion DGE under Alternative 2 to 1661.7 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than

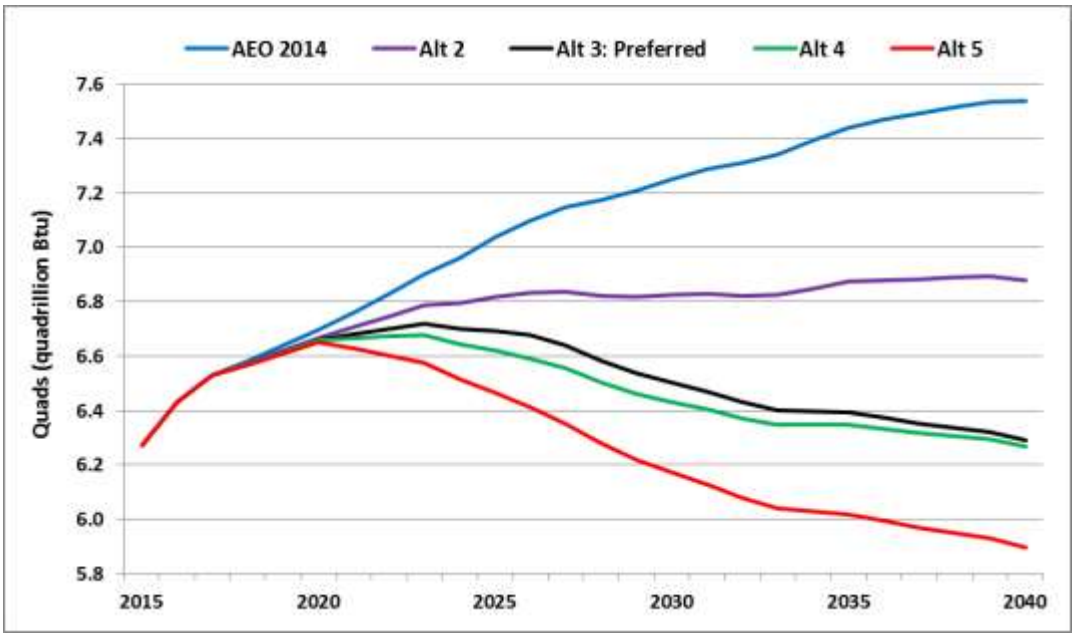
under the No Action Alternative, with total 2019–2050 cumulative fuel savings ranging from 139.1 billion DGE under Alternative 2 to 330.1 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1744.3 billion DGE, and cumulative fuel savings compared to the No Action Alternative would be 247.5 billion DGE.

3.4.3 Overall Benefits of Joint National Program

The affected environment for U.S. energy production and consumption described in Section 3.2 reflects the substantial impact of past vehicle fuel efficiency actions, including National Program standards for light-duty passenger cars and light trucks for MYs 2012–2016 and 2017–2025, and Phase 1 HD standards for MY 2014–2018. As noted in Section 3.2, these improvements in fuel efficiency, combined with slower forecast growth in vehicle miles traveled, are why the AEO 2014 forecasts much lower gasoline consumption than had been projected in the AEO 2010, as shown in Figure 3.2.2-1.

The overall benefits of 2012–2025 light-duty and 2014–2018 HD vehicle National Program standards are also evident in the forecast decline in motor gasoline consumption and the historically small increase in diesel fuel consumption through 2040, shown in Figure 3.2.2-2. Phase 2 HD standards would have only a very small incremental impact on forecast motor gasoline (and E85 and NG) consumption, because HD vehicles account for only a small fraction of motor gasoline use, but Phase 2 HD standards would have a more substantive impact on forecast transportation diesel fuel consumption, as shown in Figure 3.4.3-1.

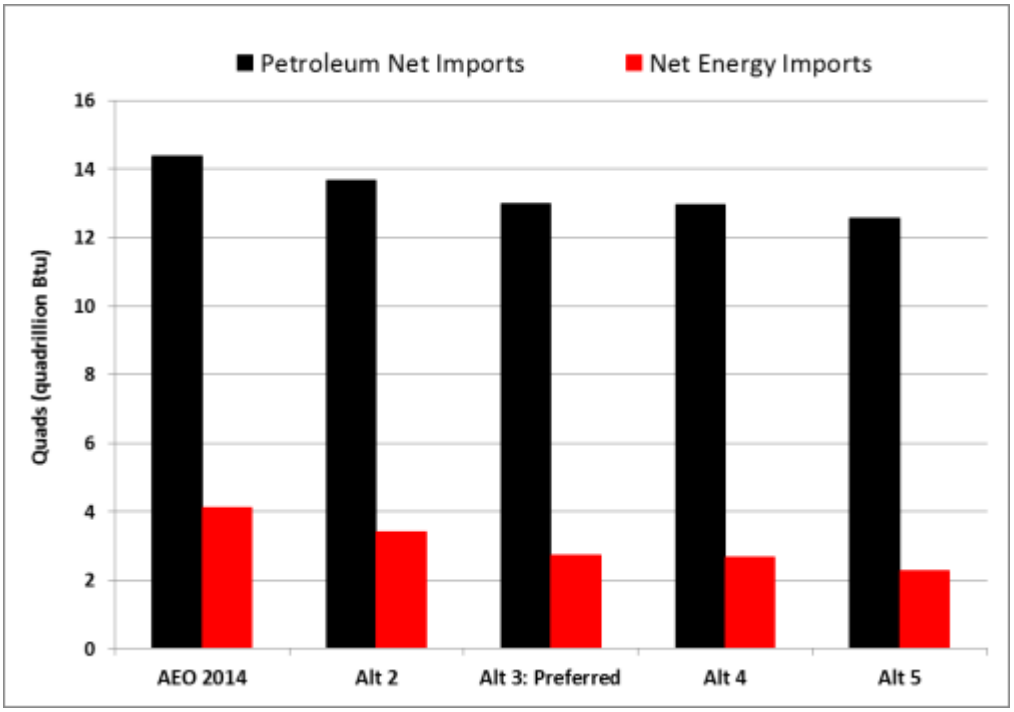
Figure 3.4.3-1. Phase 2 HD Impact on U.S. Transportation Diesel Fuel Consumption, 2015–2040



In fact, the Preferred Alternative (and Alternatives 4 and 5) would bend the AEO 2014 forecast trajectory for diesel consumption, resulting in a forecast decline in U.S. transportation diesel use beginning in the early 2020s and running through 2040. Total forecast transportation diesel consumption in 2040 under the Preferred Alternative would be back down to the transportation diesel consumption level in 2015.

Section 3.2 shows that the combination of increased U.S. energy production, more electricity generation from renewables, and gains in energy efficiency are expected to achieve large reductions in net energy imports through 2040. Phase 2 HD standards are just one component of the president's *All-of-the-Above Energy Strategy*, but the incremental impact of Phase 2 standards would further reduce U.S. net energy imports, as shown in Figure 3.4.3-2. The Preferred Alternative would reduce forecast net petroleum imports by 10 percent in 2040, and reduce overall net energy imports by 34 percent.

Figure 3.4.3-2. Phase 2 HD Impact on Projected U.S. Net Petroleum Imports and Net Energy Imports in 2040



CHAPTER 4 AIR QUALITY

The Proposed Action (including Alternative 1 [No Action Alternative], Alternative 2, Alternative 3 [Preferred Alternative], Alternative 4, and Alternative 5) would affect air pollutant emissions and air quality, which in turn, would affect public health and welfare and the natural environment. Section 4.1.1 describes the relevant air pollutants, the standards that regulate levels of these pollutants in the ambient air, their health effects, and the regulations that limit pollutant emissions rates from vehicles. Section 4.1.2 describes the approaches and methods that NHTSA used to estimate the impacts of the Proposed Action, including the national and regional analyses, the timeframes for analysis, treatment of incomplete or unavailable information, allocation of estimated emissions to nonattainment areas, and estimates of health outcomes and monetized benefits. Section 4.2.1 provides overviews of the estimated changes in criteria pollutant emissions, toxic air pollutant emissions, and health effects and monetized health benefits due to the Proposed Action. Following these overviews, Sections 4.2.1.2 through 4.2.1.6 discuss the direct and indirect impacts in detail for each alternative. Section 4.2.2 provides the same information for the estimated cumulative impacts.

4.1 Affected Environment

4.1.1 Relevant Pollutants and Standards

Many human activities cause gases and particles to be emitted into the atmosphere. These activities include driving cars and trucks; burning coal, oil, and other fossil fuels; manufacturing chemicals and other products; and smaller, everyday activities such as dry-cleaning, degreasing, painting operations, and the use of consumer products. When these gases and particles accumulate in the air in high enough concentrations, they can harm humans—especially children, the elderly, the ill, and other sensitive individuals—and can damage crops, vegetation, buildings, and other property. Many air pollutants remain in the environment for long periods and are carried by the wind hundreds of miles from their origins. People exposed to high enough levels of certain air pollutants can experience burning in their eyes, an irritated throat, breathing difficulties, or other respiratory symptoms. Long-term exposure to air pollution can cause cancer, heart and lung diseases, and damage to the immune, neurological, reproductive, and respiratory systems. In extreme cases, it can even cause death (EPA 2012a).

To reduce air pollution levels, the Federal Government and state agencies have passed legislation and established regulatory programs to control sources of emissions. The Clean Air Act (CAA) is the primary federal legislation that addresses air quality. Under the CAA, as amended, EPA has established National Ambient Air Quality Standards (NAAQS) for six criteria pollutants (relatively commonplace pollutants that can accumulate in the atmosphere as a result of normal levels of human activity).[1] The criteria pollutants analyzed in this EIS are carbon monoxide (CO), nitrogen dioxide (NO_2) (one of several oxides of nitrogen), ozone, sulfur dioxide (SO_2), particulate matter (PM) with a nominal aerodynamic diameter

[1] *Criteria pollutants* is a term used to collectively describe the six common air pollutants for which the CAA requires EPA to set NAAQS. EPA calls these pollutants criteria air pollutants because it regulates them by developing human-health based or environmentally based criteria (science-based guidelines) for setting permissible levels. *Hazardous air pollutants* refers to substances defined as hazardous by the 1990 CAA amendments. These substances include certain VOCs, compounds in PM, pesticides, herbicides, and radionuclides that present tangible hazards, based on scientific studies of human (and other mammal) exposure.

equal to or less than 10 microns (PM10) and 2.5 microns (PM2.5, or fine particles), and lead. Vehicles do not directly emit ozone, but this pollutant is evaluated based on emissions of the ozone precursor pollutants nitrogen oxides (NO_x) and volatile organic compounds (VOCs). This air quality analysis assesses the impacts of the No Action Alternative and action alternatives in relation to these criteria pollutants. It also assesses how the alternatives are projected to impact the emissions of certain hazardous air pollutants.

Total emissions from on-road mobile sources (highway vehicles) have declined dramatically since 1970 as a result of pollution controls on vehicles and regulation of the chemical content of fuels, despite continuing increases in the amount of vehicle travel. From 1970 to 2013, emissions from on-road mobile sources declined 85 percent for CO, 60 percent for NO_x, 43 percent for PM2.5, 44 percent for PM10, 89 percent for SO_2, and 87 percent for VOCs. Nevertheless, the U.S. transportation sector remains a major source of emissions of certain criteria pollutants or their chemical precursors. On-road mobile sources are responsible for 24,796,000 tons per year of CO (34 percent of total U.S. emissions), 185,000 tons per year (3 percent) of PM2.5 emissions, and 268,000 tons per year (1 percent) of PM10 emissions (EPA 2013a). HD vehicles contribute 6 percent of U.S. highway emissions of CO, 66 percent of highway emissions of PM2.5, and 55 percent of highway emissions of PM10 (Davis et al. 2013). Almost all of the PM in motor vehicle exhaust is PM2.5 (Gertler et al. 2000, EPA 2013b); therefore, this analysis focuses on PM2.5 rather than PM10. On-road mobile sources also contribute 2,161,000 tons per year (12 percent of total nationwide emissions) of VOCs and 5,010,000 tons per year (38 percent) of NO_x emissions, which are chemical precursors of ozone (EPA 2013a). HD vehicles contribute 8 percent of U.S. highway emissions of VOCs and 50 percent of NO_x (Davis et al. 2013). In addition, NO_x is a PM2.5 precursor and VOCs can be PM2.5 precursors.[2] SO_2 and other oxides of sulfur (SO_x) are important because they contribute to the formation of PM2.5 in the atmosphere; however, on-road mobile sources account for less than 0.56 percent of U.S. SO_2 emissions. With the elimination of lead in automotive gasoline, lead is no longer emitted from motor vehicles in more than negligible quantities. Therefore, this analysis does not address lead.

Table 4.1.1-1 lists the primary and secondary NAAQS for each criteria pollutant. Under the CAA, EPA sets primary standards at levels intended to protect against adverse effects on human health; secondary standards are intended to protect against adverse effects on public welfare, such as damage to agricultural crops or vegetation and damage to buildings or other property. Because each criteria pollutant has different potential effects on human health and public welfare, NAAQS specify different permissible levels for each pollutant. NAAQS for some pollutants include standards for short- and long-term average levels. Short-term standards are intended to protect against acute health effects from short-term exposure to higher levels of a pollutant; long-term standards are established to protect against chronic health effects resulting from long-term exposure to lower levels of a pollutant.

NAAQS are most commonly used to help assess the air quality of a geographic region by comparing the levels of criteria air pollutants found in the atmosphere to the levels established by NAAQS. Concentrations of criteria pollutants in the air mass of a region are measured in parts of a pollutant per million parts of air (ppm) or in micrograms of a pollutant per cubic meter of air ($\mu g/m^3$) present in repeated air samples taken at designated monitoring locations. These ambient concentrations of each

[2] NO_x can undergo chemical transformations in the atmosphere to form nitrates. VOCs can undergo chemical transformations in the atmosphere to form other various carbon compounds. Nitrates and carbon compounds can be major constituents of PM2.5. Highway vehicle emissions are large contributors to nitrate formation nationally (EPA 2004a).

criteria pollutant are compared to the permissible levels specified by NAAQS to assess whether the region's air quality could be unhealthful.

Table 4.1.1-1. National Ambient Air Quality Standards

Pollutant	Primary Standards		Secondary Standards	
	Level[a]	Averaging Time	Level[a]	Averaging Time
Carbon monoxide (CO)	9 ppm (10 mg/m^3)	8 hours[b]	None	
	35 ppm (40 mg/m^3)	1 hour[b]		
Lead	0.15 µg/m^3	Rolling 3-month average	Same as Primary	
Nitrogen dioxide (NO_2)	0.053 ppm (100 µg/m^3)	Annual (arithmetic mean)	Same as Primary	
	0.100 ppm (188 µg/m^3)	1 hour[c]	None	
Particulate matter (PM10)	150 µg/m^3	24 hours[d]	Same as Primary	
Particulate matter (PM2.5)	12.0 µg/m^3	Annual (arithmetic mean)[e]	15.0 µg/m^3	Annual (arithmetic mean)[e]
	35 µg/m^3	24 hours[f]	Same as Primary	
Ozone	0.075 ppm	8 hours[g]	Same as Primary	
Sulfur dioxide (SO_2)	0.075 ppm (200 µg/m^3)	1 hour[h]	0.5 ppm (1,300 µg/m^3)	3 hours[b]

Notes:

[a] Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air (mg/m3), and micrograms per cubic meter (µg/m^3) of air.

[b] Not to be exceeded more than once per year.

[c] To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average at each monitor within an area must not exceed 0.100 ppm (effective January 22, 2010).

[d] Not to be exceeded more than once per year on average over 3 years.

[e] To attain this standard, the 3-year average of the weighted annual mean PM2.5 concentrations from single or multiple community-oriented monitors must not exceed 12.0 µg/m^3 for the primary standard and 15.0 µg/m^3 for the secondary standard.

[f] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 µg/m^3 (effective December 17, 2006).

[g] To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor in an area over each year must not exceed 0.075 ppm (effective May 27, 2008).

[h] The 1-hour sulfur dioxide standard is attained when the 3-year average of the 99th percentile of the daily maximum 1-hour average concentrations does not exceed 0.075 ppm.

Source: 40 CFR Part 50, as presented in EPA 2011a.

CFR = Code of Federal Regulations; EPA = U.S. Environmental Protection Agency; PM10 = particulate matter with a nominal aerodynamic diameter equal to or less than 10 microns; PM2.5 = particulate matter with a nominal aerodynamic diameter equal to or less than 2.5 microns

When the measured concentrations of a criteria pollutant in a geographic region are less than those permitted by NAAQS, EPA designates the region as an "attainment" area for that pollutant; regions where concentrations of criteria pollutants exceed federal standards are called "nonattainment" areas. Former nonattainment areas that are now in compliance with NAAQS are designated as "maintenance" areas. Each state with a nonattainment area is required to develop and implement a State Implementation Plan (SIP) documenting how the region will reach attainment levels within periods specified in the CAA. For maintenance areas, the SIP must document how the state intends to maintain

compliance with NAAQS. When EPA changes a NAAQS, each state must revise its SIP to address how it plans to attain the new standard.

NAAQS have not been established for hazardous air pollutants. Hazardous air pollutants emitted from vehicles that are known or suspected to cause cancer or other serious health and environmental effects are referred to as mobile source air toxics (MSATs).[3] The MSATs included in this analysis are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter (DPM), and formaldehyde. EPA and the Federal Highway Administration (FHWA) have identified these air toxics as the MSATs that typically are of greatest concern for impacts from highway vehicles (EPA 2007, FHWA 2012). DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the PM2.5 particle-size class. On-road mobile sources are responsible for 57,440,375 tons per year (4 percent of total U.S. emissions) of acetaldehyde emissions, 4,940,766 tons per year (5 percent) of acrolein emissions, 118,251,994 tons per year (22 percent) of benzene emissions, 19,735,566 tons per year (16 percent) of 1,3-butadiene emissions, and 86,046,243 tons per year (3 percent) of formaldehyde emissions (EPA 2011b).[4]

Vehicle-related sources of air pollutants include exhaust emissions, evaporative emissions, resuspension of road dust, and tire and brake wear. Locations in close proximity to major roadways generally have elevated concentrations of many air pollutants emitted from motor vehicles. Hundreds of such studies have been published in peer-reviewed journals, concluding that concentrations of CO, nitric oxide, NO_2, benzene, aldehydes, particulate matter, black carbon, and many other compounds are elevated in ambient air within approximately 300 to 600 meters (about 1,000 to 2,000 feet) of major roadways. Studies that focused on measurements during meteorological conditions that tend to inhibit the dispersion of emissions have found that concentrations of traffic-generated air pollutants can be elevated for as much as 2,600 meters (about 8,500 feet) downwind of roads under such meteorological conditions (Hu et al. 2009, 2012). The highest concentrations of most pollutants emitted directly by motor vehicles are found at locations within 50 meters (about 165 feet) of the edge of a roadway's traffic lanes.

Air pollution near major roads has been shown to increase the risk of adverse health effects in populations who live, work, or attend school near major roads.[5] A 2013 study estimated that 19 percent of the U.S. population (over 59 million people) lived within 500 meters (about 1,600 feet) of major roads (those with at least 25,000 annual average daily traffic), while about 3.2 percent of the population (10 million people) lived within 100 meters (about 300 feet) of such roads (Rowangould 2013). Another 2013 study estimated that 3.7 percent of the U.S. population (about 11 million people) lived within 150 meters (about 500 feet) of interstate highways, or other freeways and expressways (Boehmer et al. (2013). Because of the large number of people who live near major roads, it is important to understand how traffic-generated pollutants collectively affect the health of exposed populations (EPA 2012b).

---

[3] A list of all MSATs identified by EPA to date can be found in the *Regulatory Impact Analysis for Final Rule: Control of Hazardous Air Pollutants from Mobile Sources* (signed February 9, 2007), EPA420-R-07-002, Tables 1.1-1 and 1.1-2 (EPA 2007).

[4] Nationwide total emissions data are not available for DPM.

[5] Most of the information in the remainder of this section appeared originally in the EPA 2014 final rule establishing Tier 3 motor vehicle emissions and fuel standards. *See* Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

In the past 15 years, many studies have been published with results reporting that populations who live, work, or go to school near high-traffic roadways experience higher rates of numerous adverse health effects, compared to populations far away from major roads.[6] In addition, numerous studies have found adverse health effects associated with spending time in traffic, such as commuting or walking along high-traffic roadways (Laden et al. 2007, Peters et al. 2004, Zanobetti et al. 2009, Dubowsky Adar et al. 2007). The health outcomes with the strongest evidence of linkages with traffic-associated air pollutants are respiratory effects, particularly in asthmatic children, and cardiovascular effects.

Numerous reviews of this body of health literature have been published as well. In 2010, an expert panel of the Health Effects Institute (HEI) published a review of hundreds of exposure, epidemiology, and toxicology studies (HEI 2010). The panel rated how the evidence for each type of health outcome supported a conclusion of a causal association with traffic-associated air pollution as either "sufficient," "suggestive but not sufficient," or "inadequate and insufficient." The panel categorized evidence of a causal association for exacerbation of childhood asthma as "sufficient," and categorized evidence of a causal association for new onset asthma as between "sufficient" and as "suggestive but not sufficient." The panel categorized evidence linking traffic-associated air pollutants with exacerbation of adult respiratory symptoms and lung function decrement as "suggestive of a causal association." It categorized as "inadequate and insufficient" evidence of a causal relationship between traffic-related air pollution and health care utilization for respiratory problems, new onset adult asthma, chronic obstructive pulmonary disease, non-asthmatic respiratory allergy, and cancer in adults and children. Other literature reviews have been published with conclusions generally similar to the HEI panel's (Boothe and Shendell 2008, Sun et al. 2014). However, researchers from the U.S. Centers for Disease Control and Prevention (CDC) recently published a systematic review and meta-analysis of studies evaluating the risk of childhood leukemia associated with traffic exposure, and reported positive associations between "postnatal" proximity to traffic and leukemia risks, but no such association for "prenatal" exposures (Boothe et al.2014).

Health outcomes with few publications suggest the possibility of other effects still lacking sufficient evidence to draw definitive conclusions. Among these outcomes with a small number of positive studies are neurological impacts (e.g., autism and reduced cognitive function) and reproductive outcomes (e.g., preterm birth, low birth weight) (Volk et al. 2011, Franco-Suglia et al. 2007, Power et al. 2011, Wu et al. 2011).

In addition to health outcomes, particularly cardiopulmonary effects, conclusions of numerous studies suggest mechanisms by which traffic-related air pollution affects health. Numerous studies indicate that near-roadway exposures may increase systemic inflammation, affecting organ systems, including blood vessels and lungs (Riediker 2007, Alexeef et al. 2011, Eckel et al. 2011, Zhang et al. 2009). Long-term exposures in near-road environments have been associated with inflammation-associated conditions, such as atherosclerosis and asthma (Adar et al. 2010, Kan et al. 2008, McConnell et al. 2010).

[6] The Tier 3 Final Rule reported that in the widely-used PubMed database of health publications, between January 1, 1990 and August 18, 2011, 605 publications contained the keywords "traffic, pollution, epidemiology," with approximately half the studies published after 2007.

Sections 4.1.1.1 and 4.1.1.2 discuss specific health effects associated with each of the criteria and hazardous air pollutants analyzed in this EIS. Section 5.4 addresses the major GHGs—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); this air quality analysis does not include these GHGs.

4.1.1.1 Health Effects of Criteria Pollutants

Sections 4.1.1.1.1 through 4.1.1.1.6 briefly describe the health effects of the six criteria pollutants. This information is adapted from EPA (2012c). The most recent EPA technical reports and *Federal Register* notices for NAAQS reviews provide more information on the health effects of criteria pollutants (EPA 2013c).

4.1.1.1.1 Ozone

Ozone is a photochemical oxidant and the major component of smog. Ozone is not emitted directly into the air, but is formed through complex chemical reactions among precursor emissions of VOCs and NO_x in the presence of the ultraviolet component of sunlight. Ground-level ozone causes health problems because it irritates the mucous membranes, damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants. Ozone-related health effects also include respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, and a variety of other respiratory-related effects. Exposure to ozone for several hours at relatively low concentrations has been found to substantially reduce lung function and induce respiratory inflammation in normal, healthy people during exercise. There is also evidence that short-term exposure to ozone directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality.

In addition to its human health impacts, ozone has the potential to affect the health of vegetation and ecosystems. Ozone in the atmosphere is absorbed by plants and disturbs the plant's carbon sequestration process, thereby limiting its available energy supply. Consequently, exposed plants can lose their vigor, become more susceptible to disease and other environmental stressors, and demonstrate lessened growth, visual abnormalities, or accelerated aging. According to EPA (2006), ozone affects crops, vegetation, and ecosystems more than any other air pollutant. Ozone can produce both acute and chronic injury in sensitive species, depending on the concentration level, the duration of the exposure, and the plant species under exposure. Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is consistently toxic for all plants.

VOCs, a chemical precursor to ozone, also can play a role in vegetation damage (Foster 1991). For some sensitive plants under exposure, VOCs have been demonstrated to impact seed production, photosynthetic efficiency, leaf water content, seed germination, flowering, and fruit ripening (Cape et al. 2003). NO_x, the other chemical precursor to ozone, has also been demonstrated to have impacts on vegetation health (Viskari 2000, Ugrekhelidze et al. 1997, Kammerbauer et al. 1987). Most of the studies of the impacts of VOCs and NO_x on vegetation have focused on short-term exposure; and few studies have focused on long-term effects on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

4.1.1.1.2 Particulate Matter (PM)

PM is a generic term for a broad class of chemically and physically diverse substances that exist as discrete particles. PM includes dust, dirt, soot, smoke, and liquid droplets directly emitted into the air, and particles formed in the atmosphere by condensation or by the transformation of emitted gases such as NO_x, SO_x, and VOCs. Fine particles are produced primarily by combustion processes and by these atmospheric transformations. The definition of PM also includes particles composed of elemental carbon (black carbon).[7] Gasoline-fueled and diesel-fueled vehicles emit PM. In general, the smaller the PM, the deeper it can penetrate into the respiratory system and the more damage it can cause. Depending on its size and composition, PM can damage lung tissue, aggravate existing respiratory and cardiovascular diseases, alter the body's defense systems against foreign materials, and cause cancer and premature death.

PM also can contribute to poor visibility by scattering and absorbing light, consequently making the terrain appear hazy. To address visibility concerns, EPA developed the regional haze program,[8] which was put in place in July 1999 to protect the visibility in Mandatory Class I Federal Areas (national parks and wilderness areas). EPA has also set secondary NAAQS to regulate non-Class I areas outside the regional haze program. Deposition of PM (especially secondary PM formed from NO_x and SO_x) can damage materials, adding to the effects of natural weathering processes by potentially promoting or accelerating the corrosion of metals, degrading paints, and deteriorating building materials (especially concrete and limestone). Section 7.2 provides more information about materials damage and soiling impacts.

As noted above, EPA regulates PM according to two particle-size classifications, PM10 and PM2.5. This analysis considers only PM2.5 because almost all of the PM emitted in exhaust from HD vehicles is PM2.5. EPA classifies DPM as an MSAT, so it is addressed in the air toxics section (*see* Section 4.1.1.2.5).

4.1.1.1.3 Carbon Monoxide (CO)

CO is a colorless, odorless, poisonous gas produced by incomplete combustion of carbon in fuels. Motor vehicles are the single largest source of CO emissions nationally.[9] When CO enters the bloodstream, it acts as an asphyxiant by reducing the delivery of oxygen to the body's organs and tissues. It can affect the central nervous system and impair the brain's ability to function properly. Health threats are most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Epidemiological studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease. Some epidemiological studies suggest a causal relationship between long-term

[7] Elemental carbon and black carbon are similar forms of fine PM and are considered synonymous for purposes of this analysis. The term *elemental carbon* describes carbonaceous particles based on chemical composition rather than light-absorbing characteristics. The term *black carbon* describes particles of mostly pure carbon that absorb solar radiation at all wavelengths (EPA 2012d). The carbon content of a sample of PM can be described by either term depending on the test method used: typically, the result for a sample tested by thermal or wet chemical methods is termed "elemental carbon" while the result for a sample tested by optical methods is termed "black carbon" (Andreae and Gelencser 2006).

[8] Final Rule: Regional Haze Regulations, 64 FR 35714 (July 1, 1999).

[9] Highway motor vehicles overall accounted for 34 percent of national CO emissions in 2011 (EPA 2013a). Passenger cars and light trucks accounted for approximately 89 percent of the CO emissions from highway motor vehicles (EPA 2013b) while HD vehicles accounted for most of the remaining 11 percent.

exposures to CO and developmental effects and adverse health effects at birth, such as decreased birth weight.

4.1.1.1.4 Lead

Lead is a toxic heavy metal used in industrial manufacturing and production, such as in battery manufacturing, and formerly was widely used as an additive in paints. Lead gasoline additives (for use in piston-engine-powered aircraft), non-ferrous smelters, and battery plants are the most significant contributors to atmospheric lead emissions. Lead exposure can occur through multiple pathways, including inhalation of air and ingestion of lead in food, water, soil, or dust. Excessive lead exposure can cause seizures, mental retardation, behavioral disorders, severe and permanent brain damage, and death. Even low doses of lead can cause central nervous system damage. Because of the prohibition of lead as an additive in motor vehicle liquid fuels, lead is no longer emitted from motor vehicles in more than negligible quantities. Therefore, this analysis does not address lead.

4.1.1.1.5 Sulfur Dioxide (SO_2)

SO_2, one of various oxides of sulfur, is a gas formed from combustion of fuels containing sulfur. Most SO_2 emissions are produced by stationary sources such as power plants. SO_2 is also formed when gasoline is extracted from crude oil in petroleum refineries and in other industrial processes. High concentrations of SO_2 cause severe respiratory distress (difficulty breathing), irritate the upper respiratory tract, and aggravate existing respiratory and cardiovascular disease. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction (constriction of the airways). Asthmatics are more sensitive to the effects of SO_2, likely because of preexisting bronchial inflammation. SO_2 also is a primary contributor to acidic deposition, or acid rain, which causes acidification of lakes and streams and can damage trees, crops, historic buildings, and statues.

4.1.1.1.6 Nitrogen Dioxide (NO_2)

NO_2 is a reddish-brown, highly reactive gas, one of the oxides of nitrogen formed by high-temperature combustion (as in vehicle engines) of nitrogen and oxygen. Most NO_x created in the combustion reaction consists of nitric oxide, which oxidizes to NO_2 in the atmosphere. NO_2 can irritate the lungs and mucous membranes, aggravate asthma, cause bronchitis and pneumonia, and lower resistance to respiratory infections. NO_2 has also been linked to other health outcomes, including all-cause (non-accidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and reductions in lung function growth associated with chronic exposure. Oxides of nitrogen are an important precursor to ozone and acid rain, and can affect terrestrial and aquatic ecosystems.

4.1.1.2 Health Effects of Mobile Source Air Toxics

Sections 4.1.1.2.1 through 4.1.1.2.6 briefly describe the health effects of the six priority MSATs analyzed in this EIS. This information is adapted from the Preamble to the EPA Tier 3 Motor Vehicle Emission and Fuel Standards Rule.[10]

[10] Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected to be human or animal carcinogens, or that have non-cancer health effects. The population experiences an elevated risk of cancer and other non-cancer health effects from exposure to air toxics (EPA 2005). These compounds include, but are not limited to, acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde. These five air toxics, plus DPM, comprise the six priority MSATs analyzed in this EIS. These compounds plus polycyclic organic matter (POM) and naphthalene were identified as national or regional risk drivers or contributors in the EPA 2005 National-scale Air Toxics Assessment and have significant inventory contributions from mobile sources (EPA 2005). This EIS does not analyze POM separately, but POM can occur as a component of DPM and is addressed in Section 4.1.1.2.5. Naphthalene also is not analyzed separately in this EIS, but it is a member of the POM class of compounds discussed in Section 4.1.1.2.5.

4.1.1.2.1 Acetaldehyde

Acetaldehyde is classified in the EPA Integrated Risk Information System (IRIS) database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes (EPA 1998). In its Twelfth Report on Carcinogens (NTP 2011), the U.S. Department of Health and Human Services (HHS) “reasonably anticipates” acetaldehyde to be a human carcinogen, and the International Agency for Research on Cancer (IARC) (IARC 1999) classifies acetaldehyde as possibly carcinogenic to humans (Group 2B). EPA is reassessing cancer risk from inhalation exposure to acetaldehyde and is currently in the draft development phase of the hazard identification. The expected completion date is to be determined (EPA 2014a).

The primary non-cancer effects of exposure to acetaldehyde vapors include eye, skin, and respiratory-tract irritation (EPA 1998). In short-term (4-week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure (Appelman et al. 1982, 1986). EPA used data from these studies to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume and bronchoconstriction upon inhaling acetaldehyde (Myou et al. 1993). EPA is reassessing the non-cancer health hazards from inhalation exposure to acetaldehyde on the same schedule noted above.

4.1.1.2.2 Acrolein

Acrolein is extremely acrid and is irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion, and congestion. The intense irritancy of this carbonyl compound has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure (EPA 2003a). The EPA 2003 IRIS human health risk assessment for acrolein (EPA 2003a) summarizes these data and additional studies regarding acute effects of human exposure to acrolein. Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 milligram per cubic meter) for 5 minutes can elicit subjective complaints of eye irritation, with increasing concentrations leading to more extensive eye, nose, and respiratory symptoms (Weber-Tschopp et al. 1977, EPA 2003a). Lesions to the lungs and upper respiratory tracts of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein (EPA 2003b). Acute exposure effects in animal studies report bronchial hyper-responsiveness (EPA 2003a). In a recent study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease compared to non-diseased mice, which also showed decreases in respiratory rate (Morris et al. 2003). Based on these animal data and demonstration of similar effects in humans (e.g., reduction in respiratory rate), individuals with

compromised respiratory function (e.g., emphysema and asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

IARC determined that acrolein was not classifiable as to its carcinogenicity in humans (IARC 1995), and EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans, and the animal data provided inadequate evidence of carcinogenicity (EPA 2003b).

4.1.1.2.3 Benzene

EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice (EPA 2000a, IARC 1982, Irons et al. 1992). Data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. IARC and HHS have characterized benzene as a human carcinogen (IARC 1987, NTP 2011).

Several adverse non-cancer health effects, including blood disorders such as pre-leukemia and aplastic anemia, have also been associated with long-term exposure to benzene (Aksoy 1989, Goldstein 1988). The most sensitive non-cancer effect observed in humans, based on current data, is depression of the absolute lymphocyte count in blood (Rothman et al. 1996, EPA 2002a). In addition, recent work, including studies sponsored by the Health Effects Institute, provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known (Qu et al. 2002, 2003, Lan et al. 2004, Turtletaub and Mani 2003). The EPA IRIS program has not yet reported any evaluation of these newer data (EPA 2013d).

4.1.1.2.4 1,3-butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans through inhalation (EPA 2002b, 2002c). IARC has determined that 1,3-butadiene is a probable human carcinogen, and HHS has characterized 1,3-butadiene as a known human carcinogen (IARC 1999, NTP 2011). Numerous experiments have demonstrated that animals and humans metabolize 1,3-butadiene into compounds that are genotoxic (capable of causing damage to a cell's genetic material such as deoxyribonucleic acid [DNA]). The specific mechanisms of 1,3-butadiene-induced carcinogenesis are not known; however, scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females could be more sensitive than males for cancer effects associated with 1,3-butadiene exposure. There are insufficient data on humans from which to draw conclusions about sensitive subpopulations. 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; there are no available human data on these effects. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice (Bevan et al. 1996).

4.1.1.2.5 Diesel Particulate Matter (DPM)

Diesel exhaust consists of a complex mixture composed of CO_2, oxygen, nitrogen, water vapor, CO, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic, including aldehydes, benzene and 1,3-butadiene. The DPM present in diesel exhaust consists mostly of fine particles (smaller

than 2.5 microns), of which a significant fraction is ultrafine particles (smaller than 0.1 micron). These particles have a large surface area, which makes them an excellent medium for adsorbing organics, and their small size makes them highly respirable. Many of the organic compounds present in the gases and on the particles, such as polycyclic organic matter, are individually known to have mutagenic and carcinogenic properties.

DPM also includes elemental carbon (i.e., black carbon) particles emitted from diesel engines. EPA has not provided special status, such as an NAAQS or other health-protective measures, for black carbon, but addresses black carbon in terms of PM2.5 and DPM emissions.

Diesel exhaust varies significantly in chemical composition and particle sizes between different engine types (heavy-duty, light-duty), engine operating conditions (idle, acceleration, deceleration), and fuel formulations (high/low sulfur fuel). Also, there are emissions differences between on-road and non-road engines because the non-road engines are generally of older technology. After being emitted in the engine exhaust, diesel exhaust undergoes dilution, as well as chemical and physical changes in the atmosphere. The lifetime for some of the compounds present in diesel exhaust ranges from hours to days.

In EPA's 2002 *Diesel Health Assessment Document* (Diesel HAD) (EPA 2002d), exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996–1999 EPA cancer guidelines (EPA 1999a). A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) had made similar hazard classifications prior to 2002. EPA also concluded in the 2002 Diesel HAD that it was not possible to calculate a cancer unit risk for diesel exhaust due to limitations in the exposure data for the occupational groups or the absence of a dose-response relationship.

In the absence of a cancer unit risk, the Diesel HAD sought to provide additional insight into the significance of the diesel exhaust cancer hazard by estimating possible ranges of risk that might be present in the population. An exploratory analysis was used to characterize a range of possible lung cancer risk. The outcome was that environmental risks of cancer from long-term diesel exhaust exposures could plausibly range from as low as 10^{-5} to as high as 10^{-3}. Because of uncertainties, the analysis acknowledged that the risks could be lower than 10^{-5}, and a zero risk from diesel exhaust exposure could not be ruled out.

Non-cancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to EPA. EPA derived a diesel exhaust reference concentration (RfC) from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects. The RfC is 5 $\mu g/m^3$ for diesel exhaust measured as DPM. This RfC does not consider allergenic effects such as those associated with asthma or immunologic effects or the potential for cardiac effects. There was emerging evidence in 2002, discussed in the Diesel HAD, that exposure to diesel exhaust can exacerbate these effects, but the exposure-response data were lacking at that time to derive an RfC based on these then-emerging considerations. The EPA Diesel HAD states, "With [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing [diesel exhaust] non-cancer database to identify all of the pertinent [diesel exhaust]-caused non-cancer health hazards." The Diesel HAD also notes "that acute exposure to [diesel exhaust] has been associated with irritation of the eye, nose, and throat, respiratory symptoms (cough and phlegm), and neurophysiological symptoms such as headache, lightheadedness, nausea, vomiting, and numbness or tingling of the extremities." The

Diesel HAD notes that the cancer and non-cancer hazard conclusions applied to the general use of diesel engines then on the market and as cleaner engines replace a substantial number of existing ones, the applicability of the conclusions would need to be reevaluated.

The Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses EPA's then-annual PM2.5 NAAQS of 15 µg/m^3. In 2012, EPA revised the annual PM2.5 NAAQS to 12 µg/m^3. There is a large and extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The PM2.5 NAAQS is designed to provide protection from the non-cancer health effects and premature mortality attributed to exposure to PM2.5. The contribution of diesel PM to total ambient PM varies in different regions of the country and also, within a region, from one area to another. The contribution can be high in near-roadway environments, for example, or in other locations where diesel engine use is concentrated.

Since 2002, several new studies have been published, which continue to report increased lung cancer risk with occupational exposure to diesel exhaust from older engines. Of particular note since 2011, are three new epidemiology studies that have examined lung cancer in occupational populations, for example, truck drivers, underground non-metal miners and other diesel-motor-related occupations (Garshick et al. 2012, Silverman et al. 2012, Olsson et al. 2012). These studies reported increased risk of lung cancer with exposure to diesel exhaust with evidence of positive exposure-response relationships to varying degrees. These newer studies—along with others that have appeared in the scientific literature—add to the evidence EPA evaluated in the 2002 Diesel HAD and further reinforces the concern that diesel exhaust exposure likely poses a lung cancer hazard. The findings from these newer studies do not necessarily apply to newer technology diesel engines since the newer engines have large reductions in the emissions constituents compared to older-technology diesel engines.

In light of the growing body of scientific literature evaluating the health effects of exposure to diesel exhaust, in June 2012, the World Health Organization's International Agency for Research on Cancer (IARC), a recognized international authority on the carcinogenic potential of chemicals and other agents, evaluated the full range of cancer-related health effects data for diesel engine exhaust. IARC concluded that diesel exhaust should be regarded as "carcinogenic to humans" (IARC 2013). This designation was an update from its 1988 evaluation that considered the evidence to be indicative of a "probable human carcinogen."

4.1.1.2.6 Formaldehyde

In 1991, EPA concluded that formaldehyde is a carcinogen based on nasal tumors in animal bioassays (EPA 1989). EPA developed an Inhalation Unit Risk for cancer and a Reference Dose for oral non-cancer effects and posted them in the IRIS database. Since that time, the National Toxicology Program and IARC have concluded that formaldehyde is a known human carcinogen (NTP 2011, IARC 2006, and IARC 2012).

The conclusions by IARC and the National Toxicology Program reflect the results of epidemiologic research published since 1991, in combination with previous animal, human, and mechanistic evidence. Research by the National Cancer Institute reported an increased risk of nasopharyngeal (nose and throat) cancer and specific lymphohematopoietic (lymph and blood) malignancies among workers exposed to formaldehyde (Hauptmann et al. 2003, 2004, and Beane Freeman et al. 2009). A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of

death due to leukemia among workers exposed to formaldehyde (Pinkerton et al. 2004). Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported (Coggon et al. 2003). Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid (bone marrow cell) leukemia, but not brain cancer (Hauptmann et al. 2009).

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999 (ATSDR 1999) and supplemented in 2010 (ATSDR 2010), and by the World Health Organization (IPCS 2010). These organizations reviewed the literature concerning effects on the eyes and respiratory system, the primary point of contact for inhaled formaldehyde, including sensory irritation of eyes, and respiratory tract, pulmonary function, nasal histopathology, and immune system effects. In addition, research on reproductive and developmental effects and neurological effects were discussed along with several studies that suggest formaldehyde may increase the risk of asthma, particularly in the young. EPA released a draft Toxicological Review of Formaldehyde – Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment in June 2010 (EPA 2010a). The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011 (NRC 2011a). The EPA is currently revising the draft assessment in response to this review (EPA 2014b).

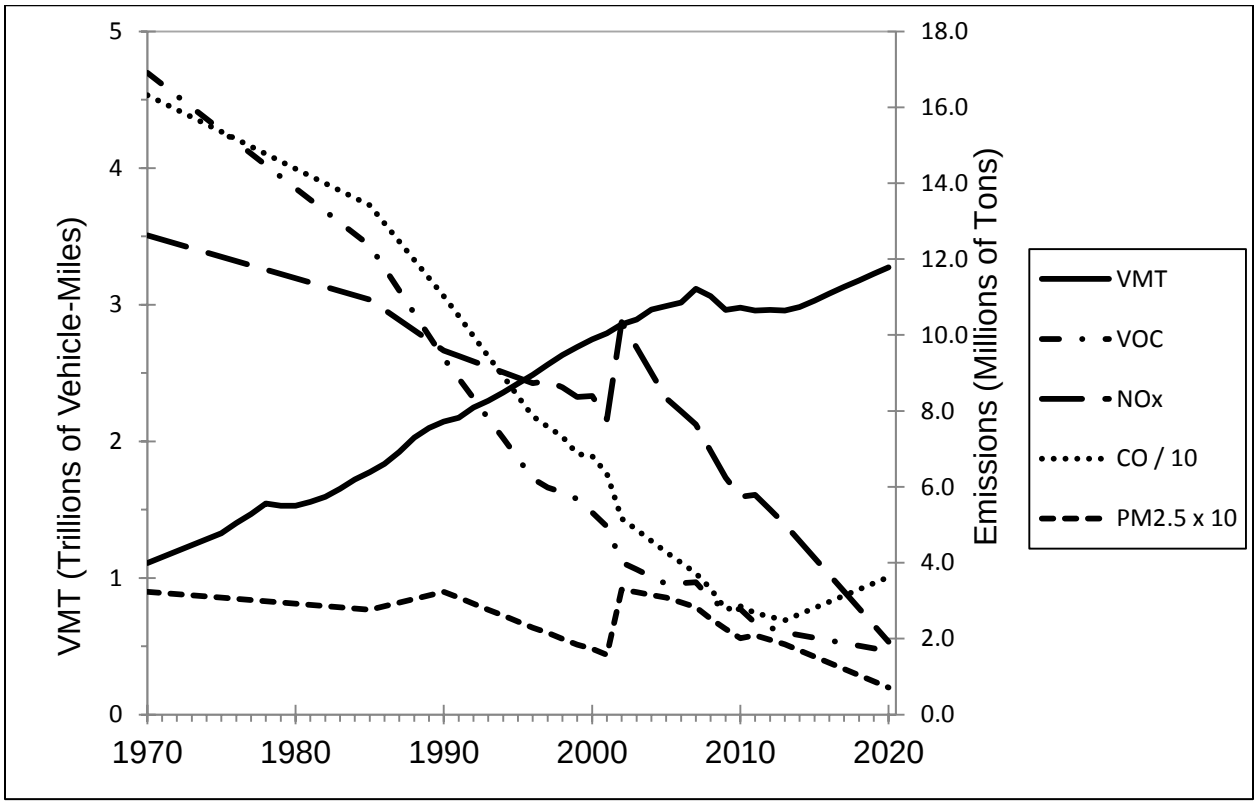
4.1.1.3 Vehicle Emissions Standards

EPA has established criteria pollutant emissions standards for vehicles under the CAA. EPA has tightened these emissions standards over time as more effective emissions-control technologies have become available. These stricter standards for passenger cars and light trucks and for HD vehicles are responsible for the declines in total criteria pollutant emissions from motor vehicles, as discussed in Section 4.1.1. The EPA Tier 2 Vehicle & Gasoline Sulfur Program, which went into effect in 2004, established the CAA emissions standards that will apply to MY 2017–2025 passenger cars and light trucks (EPA 2000b). Under the Tier 2 standards, manufacturers of passenger cars and light trucks are required to meet stricter vehicle emissions limits than under the previous Tier 1 standards. By 2006, U.S. refiners and importers of gasoline were required under the Tier 2 standards to manufacture gasoline with an average sulfur level of 30 ppm, a 90 percent reduction from earlier sulfur levels. These fuels enable post-2006 model year vehicles to use emissions-control technologies that reduce tailpipe emissions of NO_x by 77 percent for passenger cars and by as much as 95 percent for pickup trucks, vans, and sport utility vehicles compared to 2003 levels. On April 28, 2014, EPA issued a final rule establishing Tier 3 motor vehicle emissions and fuel standards.[11] The Tier 3 vehicle standards reduce both tailpipe and evaporative emissions from passenger cars, light-duty trucks, medium-duty passenger vehicles, and Classes 2b–3 heavy-duty vehicles. Starting in 2017, Tier 3 sets new vehicle emissions standards and lowers the sulfur content of gasoline, considering the vehicle and its fuel as an integrated system. The Tier 3 program will require an approximate 60 percent reduction in new Classes 2b–3 vehicle NO_X, PM, VOCs and formaldehyde emissions. The Tier 3 gasoline sulfur standard will make emissions-control systems more effective for both existing and new vehicles, and will enable more stringent vehicle emissions standards (EPA 2014c).

[11] Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

EPA adopted new emissions-control requirements for heavy-duty highway engines and vehicles on October 6, 2000 (65 *FR* 59896) and January 18, 2001 (66 *FR* 5002). These rules also required that the Nation's refiners and importers of diesel fuel manufacture diesel fuel with sulfur levels capped at 15 ppm, an approximately 97-percent reduction from the previous maximum of 500 ppm. This fuel, known as ultra-low-sulfur diesel fuel, enables post-2006 model year heavy-duty vehicles to use emissions controls that reduce exhaust (tailpipe) emissions of NO_x by 95 percent and PM by 90 percent, compared to 2003 model year levels. As a result of these programs, new trucks meeting current emissions standards emit 98 percent less NO_x and 99 percent less PM than new trucks emitted 20 years ago.[12] Figure 4.1.1-1 illustrates current trends in travel and emissions from highway vehicles, not accounting for the effects of the Proposed Action and alternatives; *see* Section 4.2.

Figure 4.1.1-1. Vehicle Miles Traveled Compared to Vehicle Emissions[a,b]



[a] Because CO emissions are generally about 10 times higher than emissions of NOx, SOx, and VOCs, and emissions of PM2.5 are about 10 times lower than emissions of NOx, SOx, and VOCs, the scales for CO and PM2.5 are proportionally adjusted to enable comparison of trends among pollutants.

[b] Apparent increases in NOx and PM2.5 emissions in 2002 are due to a methodology change made by EPA in 2012 from the MOBILE6.2 model to the MOVES model to calculate emissions for years 2002 and later (EPA 2013b.

Sources: Davis et al. 2013, EPA 2011b, EPA 2013a, EPA 2013b, EIA 2014a, IEC 2011.

VMT = vehicle miles traveled; VOCs = volatile organic compounds; NOx = nitrogen oxides; CO = carbon monoxide; PM2.5 = particulate matter with a diameter of 2.5 microns or less.

[12] Model year 1984 heavy-duty engines met standards of 10.7 grams per brake horsepower-hour (g/bhp-hr) NO_x and 0.6 g/bhp-hr PM; model year 2007 and later heavy-duty engines meet standards of 0.2 g/bhp-hr NO_x and 0.01 g/bhp-hr PM.

Since 1970, aggregate emissions traditionally associated with vehicles have decreased substantially even as vehicle miles traveled (VMT) increased by approximately 142 percent from 1970 to 1999, and approximately 166 percent from 1970 to 2011, as shown in Figure 4.1.1-1. For example, NO_x emissions, due mainly to light trucks and heavy-duty vehicles, decreased by 60 percent between 1970 and 2013, as shown in Figure 4.1.1-1 (EPA 2013a). However, as future trends show, changes in vehicle travel are having a smaller and smaller impact on emissions as a result of stricter EPA standards for vehicle emissions and the chemical composition of fuels, even with additional growth in VMT (Smith 2002). This general trend will continue, to a greater or lesser degree, with implementation of any of the action alternatives. MSAT emissions will likely decrease in the future because of recent EPA rules (EPA 2007). These rules limited the benzene content of gasoline beginning in 2011. They also limit exhaust emissions of hydrocarbons (many VOCs and MSATs are hydrocarbons) from passenger cars and light trucks when they are operated at cold temperatures. The cold-temperature standard is being phased in from 2010 through 2015. EPA projects that these controls will substantially reduce emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde.

4.1.1.4 Conformity Regulations

The CAA prohibits a federal agency from engaging in or supporting an activity that does not "conform" to a State Implementation Plan (SIP) or federal Implementation Plan after EPA has approved or promulgated it, or that would affect a state's compliance with the NAAQS. 42 U.S.C. § 7506(c)(1). The purpose of the conformity requirement is to ensure that activities do not interfere with meeting the emissions targets in SIPs, do not cause or contribute to new violations of the NAAQS, and do not impede the ability of a state to attain or maintain NAAQS or delay any interim milestones. EPA has issued two sets of regulations to implement the conformity requirements:

- The Transportation Conformity Rule (40 CFR part 51, Subpart T and part 93, Subpart A), which applies to transportation plans, programs, and projects funded or approved under Title 23 U.S.C. or Title 49 U.S.C., Chapter 53 (Public Transportation).
- The General Conformity Rule (40 CFR part 51, Subpart W and part 93, Subpart B), which applies to all other federal actions not covered under transportation conformity. The General Conformity Rule establishes emissions thresholds for use in evaluating the conformity of an action that results in emissions increases. *See* 40 CFR 93.153(b). If the net increases of direct and indirect emissions are lower than these thresholds, then the action is presumed to conform and no further conformity evaluation is required. If the net increases of direct and indirect emissions exceed any of these thresholds, and the action is not otherwise exempt, then a conformity determination is required. The conformity determination can entail air quality modeling studies, consultations with EPA and state air quality agencies, and commitments to revise the SIPs or to implement measures to mitigate air quality impacts.

The proposed HD vehicle fuel efficiency standards and associated program activities are not funded or approved under Title 23 U.S.C. or Title 49 U.S.C., Chapter 53. Further, the proposed standards are not a highway or transit project funded or approved by FHWA or the Federal Transit Administration. Accordingly, this action and associated program activities are not subject to the Transportation Conformity Rule. Instead, we evaluate the applicability of the General Conformity Rule.

Under the General Conformity Rule, a conformity determination is required where a federal action would result in total direct and indirect emissions of a criteria pollutant or precursor originating in nonattainment or maintenance areas equaling or exceeding the rates specified in 40 CFR § 93.153(b)(1)

and (2). As explained below, NHTSA's Proposed Action results in neither direct nor indirect emissions as defined at 40 CFR § 93.152.

The General Conformity Rule defines direct emissions as "those emissions of a criteria pollutant or its precursors that are caused or initiated by the federal action and originate in a nonattainment or maintenance area and occur at the same time and place as the action and are reasonably foreseeable." 40 CFR § 93.152. Because NHTSA's Proposed Action would set fuel efficiency standards for HD vehicles, it causes no direct emissions within the meaning of the General Conformity Rule. *See Department of Transportation v. Public Citizen*, 541 U.S. 752, 772 (2004) ("[T]he emissions from the Mexican trucks are not 'direct' because they will not occur at the same time or at the same place as the promulgation of the regulations.").

Indirect emissions under the General Conformity Rule are "those emissions of a criteria pollutant or its precursors (1) That are caused or initiated by the federal action and originate in the same nonattainment or maintenance area but occur at a different time or place as the action; (2) That are reasonably foreseeable; (3) That the agency can practically control; and (4) For which the agency has continuing program responsibility." 40 CFR § 93.152. Each element of the definition must be met to qualify as an indirect emission. NHTSA has determined that, for purposes of general conformity, emissions that may result from the fuel efficiency standards would not be caused by NHTSA's action, but rather occur due to subsequent activities the agency cannot practically control. "[E]ven if a Federal licensing, rulemaking, or other approving action is a required initial step for a subsequent activity that causes emissions, such initial steps do not mean that a Federal agency can practically control any resulting emissions."[13] 40 CFR § 93.152.

As the fuel efficiency improvement program uses performance-based standards, NHTSA cannot control the technologies vehicle manufacturers' use to improve the fuel efficiency of HD vehicles. Furthermore, NHTSA cannot control consumer purchasing and driving behavior (e.g., the rebound effect). For purposes of analyzing the environmental impacts of the Proposed Action under NEPA, NHTSA has made assumptions regarding the technologies manufacturers will install and how companies will react to increased fuel efficiency standards. Specifically, NHTSA's NEPA analysis predicts that increases in air toxic and criteria pollutants would occur in some nonattainment areas under certain alternatives based on the rebound effect. However, NHTSA's Proposed Action does not mandate specific manufacturer decisions or driver behavior, and NHTSA cannot control either. *See*, e.g., *Department of Transportation v. Public Citizen*, 541 U.S. 752, 772-73 (2004); *South Coast Air Quality Management District v. Federal Energy Regulatory Commission*, 621 F.3d 1085, 1101 (9th Cir. 2010).

NHTSA's NEPA analysis assumes a rebound effect, wherein the Proposed Action could create an incentive for additional vehicle use by reducing the relative cost of fuel. This rebound effect is an estimate of how NHTSA assumes some drivers and motor carriers will react to the proposed rule and is important for estimating the costs and benefits of the rule, but the agency does not have the statutory authority or the program responsibility to control, among other items discussed above, the actual VMT by drivers. Accordingly, changes in any emissions that result from NHTSA's proposed standards are not changes the agency can practically control. Therefore, the Proposed Action would cause no indirect emissions under the General Conformity Rule, and a general conformity determination is not required.

[13] Final Rule: Revisions to the General Conformity Regulations, 75 FR 17254 (Apr. 5, 2010).

4.1.2 Methodology

This section describes the approaches and methods that NHTSA used to estimate the impacts of the Proposed Action, including an overview (Section 4.1.2.1), regional analysis (Section 4.1.2.2), timeframes for analysis (Section 4.1.2.3), treatment of incomplete or unavailable information (Section 4.1.2.4), allocation of estimated emissions to nonattainment areas (Sections 4.1.2.5 and 4.1.2.6), and estimates of health outcomes and monetized benefits (Section 4.1.2.7).

4.1.2.1 Overview

To analyze air quality and human health impacts, NHTSA calculated the emissions of criteria pollutants and MSATs from HD vehicles that would occur under each alternative. NHTSA then estimated the resulting changes in emissions under each action alternative by comparing emissions under that alternative to those under the No Action Alternative. The resulting changes in air quality and effects on human health were assumed to be proportional to the changes in emissions projected to occur under each action alternative.

The air quality analysis accounted for downstream emissions, upstream emissions, and the rebound effect, as discussed in Section 2.4.1. In summary, the change in emissions resulting from each alternative is the sum of (1) changes in upstream emissions, which usually are reductions due to the decline in fuel consumption and, therefore, a lower volume of fuel production and distribution, (2) decreases (usually) in per-vehicle (downstream) emissions rates resulting from application of fuel efficiency technologies, and (3) the increase in vehicle (downstream) emissions resulting from added vehicle use due to the fuel-efficiency rebound effect.

As discussed in Chapter 2, the air quality results presented in this chapter, including impacts to human health, are based on a number of assumptions about the type and rate of emissions from the combustion of fossil fuels. In addition to tailpipe emissions, this analysis accounts for upstream emissions from the production and distribution of fuels. To estimate upstream emissions changes resulting from decreased downstream fuel consumption, the analysis uses a spreadsheet model developed by EPA and based on emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (2013 version developed by the U.S. Department of Energy [DOE] Argonne National Laboratory). The spreadsheet model uses the decreased volumes of the fuels along with the emissions factors from GREET for the various fuel production and transport processes to estimate the net changes in upstream emissions as a result of fuel consumption changes.

4.1.2.2 Regional Analysis

Over the course of the development of recent CAFE EISs and the Phase 1 EIS, NHTSA received comments requesting that the agency consider the sub-national air quality impacts of these programs. NHTSA has included the following information about regional air quality impacts of the Proposed Action in response to such comments and because the agency believes that such an analysis provides valuable information for the decisionmaker, state and local authorities, and the general public. Performing this analysis does not affect the agency's conclusion that a general conformity determination is not required. While a truly local analysis (i.e., at the individual roadway level) is impractical for a nationwide EIS, NHTSA believes a regional emissions analysis still provides valuable information and is feasible for the scope of this analysis.

To assess regional differences in the effects of the alternatives, NHTSA estimated net emissions changes for individual nonattainment and maintenance areas. The distribution of emissions is not uniform nationwide, and either increases or decreases in emissions can occur within individual nonattainment and maintenance areas. NHTSA focused on nonattainment and maintenance areas because these are the regions in which air quality problems have been greatest. NHTSA assessed only areas that are in nonattainment or maintenance for ozone or PM2.5 because these are the pollutants for which emissions from HD vehicles are of greatest concern. At present, there are no CO or NO_2 nonattainment areas. There are many areas designated as being in nonattainment for SO_2 or PM10. There are also maintenance areas for CO, NO_2, PM10, and SO_2. NHTSA did not quantify PM10 emissions separately from PM2.5 because almost all the PM in the exhaust from HD vehicles is PM2.5.[14] Appendix B provides emissions estimates for all nonattainment and maintenance areas for all criteria pollutants (except lead, as explained in Section 4.1.1.1.4). On-road motor vehicles are a minor contributor to SO_2 emissions (less than 0.56 percent of national emissions, as noted above) and are unlikely to affect the attainment status of SO_2 nonattainment and maintenance areas.

NHTSA's emissions analysis is national and regional, but does not attempt to address the specific geographic locations of increases in emissions within nonattainment and maintenance areas. Emissions increases due to the rebound effect consist of higher emissions from HD vehicles operating on entire regional roadway networks, so that any emissions increases due to the VMT rebound effect would be distributed throughout a region's entire road network, and at any specific location would be uniformly proportional to VMT increases at that location. At any one location within a regional network, the resulting increase in emissions would be small compared to total emissions from all sources surrounding that location (including existing emissions from traffic already using the road), so the localized impacts of the Proposed Action on ambient concentrations and health should also be small. The nationwide aggregated consequences of such small near-source impacts on ambient pollutant concentrations and health might be larger, but are not feasible to quantify.

4.1.2.3 Timeframes for Analysis

Ground-level concentrations of criteria and toxic air pollutants generally respond quickly to changes in emissions rates. The longest averaging period for measuring whether ambient concentrations of a pollutant comply with the NAAQS is 1 year.[15] This air quality analysis considers emissions that would occur over annual periods, consistent with the NAAQS. To evaluate impacts to air quality, specific years must be selected for which emissions will be estimated and their effects on air quality calculated.

NHTSA selected calendar years that are meaningful for the timing of likely effects of the alternatives, as follows.

- **2018:** A baseline/early forecast year; last year in which new HD vehicles are generally required to meet fuel efficiency standards that increase over the previous year, as set forth under NHTSA's Phase 1 HD Fuel Efficiency Improvement Program. (Phase 1 fuel efficiency standards remain the same for subsequent years until the Proposed Action takes effect.)

[14] In addition to exhaust PM2.5, the analysis included the brake wear and tire wear components of PM2.5.

[15] Compliance with the ozone NAAQS is based on the average of the fourth highest daily maximum 8-hour concentration over a 3-year period; compliance with the 24-hour PM2.5 NAAQS is based on the average of the daily 98th-percentile concentrations averaged over a 3-year period; and compliance with the annual PM2.5 NAAQS is based on the 3-year average of the weighted annual mean concentrations.

- **2025:** An early forecast year; by this point about half of HD vehicle VMT would be accounted for by vehicles that meet fuel efficiency standards as set forth under the Proposed Action.
- **2035:** A mid-term forecast year; by this point a large proportion of HD vehicle VMT would be accounted for by vehicles that meet fuel efficiency standards as set forth under the Proposed Action.
- **2050:** By 2050, almost all HD vehicles in operation would meet fuel efficiency standards as set forth under the Proposed Action, and changes in year-over-year impacts would be determined primarily by VMT growth rather than by MY 2021–2027 HD vehicles (MY 2018–2027 HD trailers) replacing older, less fuel-efficient HD vehicles.

4.1.2.4 Incomplete or Unavailable Information

Where information in the analysis included in this EIS is incomplete or unavailable, NHTSA relies on CEQ regulations regarding incomplete or unavailable information (*see* 40 CFR § 1502.22(b)). As noted throughout this methodology section, the estimates of emissions rely on models and forecasts that contain numerous assumptions and data that are uncertain. Examples of areas in which information is uncertain (and therefore may be incomplete or unavailable) include future emissions rates, vehicle manufacturers' decisions about vehicle technology and design, the mix of vehicle types and model years comprising the HD vehicle fleet, VMT projections, emissions from fuel refining and distribution, and economic factors.

To support the information in this EIS, NHTSA used the best available models and supporting data. The models used for the EIS were subjected to scientific review and have received the approval of the agencies that sponsored their development. Nonetheless, NHTSA notes that there are limitations to current modeling capabilities. For example, uncertainties can derive from model formulation (including numerical approximations and the definition of physical and chemical processes) and inaccuracies in the input data (e.g., emissions inventory estimates).

Additional limitations are associated with the estimates of health benefits. To approximate the health benefits associated with each alternative, NHTSA used screening-level estimates of health outcomes in the form of cases per ton of criteria pollutant emissions reduced, and of monetized health benefits in the form of dollars per ton of criteria pollutant emissions reduced. However, the use of such dollars-per-ton numbers does not account for all potential health and environmental benefits because the information necessary to monetize all potential health and environmental benefits is not available. Therefore, NHTSA has likely underestimated the total benefits of reducing criteria pollutants. Reductions in emissions of toxic air pollutants should also result in health benefits, but scientific data that would support quantification and monetization of these benefits are not available.

4.1.2.5 Allocation of Exhaust Emissions to Nonattainment Areas[16]

For each alternative, the Volpe and MOVES models provided national emissions estimates for each criteria air pollutant (or its chemical precursors) and MSAT. National emissions were allocated to the county level using VMT data for each county. EPA provided estimated HD vehicle VMT data for all

[16] In Sections 4.1.2.5 and 4.1.2.6, where the term *nonattainment* is used, it includes both nonattainment areas and maintenance areas.

counties in the United States, consistent with EPA's National Emissions Inventory (NEI).[17] VMT data used in the NEI were estimated from traffic counts taken by counties and states on major roadways, and therefore are subject to some uncertainty. NHTSA used the estimates of county-level VMT from the NEI only to allocate nationwide total emissions to counties, and not to calculate the county-level emissions directly. The estimates of nationwide total emissions are based on the national VMT data used in the Volpe and MOVES models.

NHTSA used the county-level VMT allocations, expressed as the fractions of national VMT that takes place within each county, to derive the county-level emissions from the estimates of nationwide total emissions. Emissions for each nonattainment area were then derived by summing the emissions for the counties included in each nonattainment area. Many nonattainment areas comprise one or more counties, and because county-level emissions are aggregated for each nonattainment area, uncertainties in the county-level emissions estimates carry over to estimates of emissions within each nonattainment area. Over time, some counties will grow faster than others, and VMT growth rates will also vary. EPA's estimate of county-level VMT allocation is constant over time, which introduces some uncertainty into the nonattainment-area-level VMT estimates for future years. Additional uncertainties that affect county-level exhaust emissions estimates arise from differences among counties or nonattainment areas in factors other than VMT, such as ambient temperatures, vehicle age distributions, vehicle speed distributions, vehicle inspection and maintenance programs, and fuel composition requirements. This uncertainty increases as the projection period lengthens, such as for analysis years 2035 and 2050 compared with analysis years 2018 and 2025.

The geographic definitions of ozone and PM2.5 nonattainment areas NHTSA uses in this document came from the current EPA Green Book Nonattainment Areas for Criteria Pollutants (EPA 2013e). For nonattainment areas that include portions of counties, NHTSA calculated the proportion of county population that falls within the nonattainment area boundary as a proxy for the proportion of county VMT within the nonattainment area boundary. Partial county boundaries were taken from geographic information system (GIS) files based on 2013 nonattainment area definitions. The populations of these partial-county areas were calculated using U.S. Census data applied to the boundaries mapped by GIS. This method assumes that per-capita VMT is constant in each county, so that the proportion of county-wide VMT in the partial county area reflects the proportion of total county population residing in that same area. This technique for allocating VMT to partial counties involves some additional uncertainty because actual VMT per capita can vary according to the characteristics of land use and urban development. For example, VMT per capita can be lower than average in urban centers with mass transit, and higher than average in suburban and rural areas where people tend to drive more (Cook et al. 2006).

Table 4.1.2-1 lists the current nonattainment and maintenance areas for ozone and PM2.5 and their status/classification and general conformity threshold.

[17] The VMT data provided by EPA are based on data generated by the Federal Highway Administration.

Table 4.1.2-1. Nonattainment Areas for Ozone and PM2.5

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Albany-Schenectady-Troy, NY	Ozone	Former Subpart 1	50
Allegan County, MI	Ozone	Former Subpart 1	50
Allentown-Bethlehem-Easton, PA	Ozone	Maintenance	100
Allentown-Bethlehem-Easton, PA	PM2.5	Nonattainment	100
Altoona, PA	Ozone	Maintenance	100
Amador and Calaveras Counties (Central Mountain), CA	Ozone	Former Subpart 1	50
Atlanta, GA	Ozone	Moderate	50
Atlanta, GA	PM2.5	Nonattainment	100
Baltimore, MD	Ozone	Moderate	50
Baltimore, MD	PM2.5	Nonattainment	100
Baton Rouge, LA	Ozone	Moderate	50
Beaumont-Port Arthur, TX	Ozone	Moderate	50
Benton Harbor, MI	Ozone	Maintenance	100
Benzie County, MI	Ozone	Maintenance	100
Birmingham, AL	Ozone	Maintenance	100
Birmingham, AL	PM2.5	Nonattainment	100
Boston-Lawrence-Worcester (eastern MA), MA	Ozone	Moderate	50
Boston-Manchester-Portsmouth (southeast NH), NH	Ozone	Moderate	50
Buffalo-Niagara Falls, NY	Ozone	Former Subpart 1	50
Canton-Massillon, OH	Ozone	Maintenance	100
Canton-Massillon, OH	PM2.5	Nonattainment	100
Cass County, MI	Ozone	Maintenance	100
Charleston, WV	Ozone	Maintenance	100
Charleston, WV	PM2.5	Nonattainment	100
Charlotte-Gastonia-Rock Hill, NC-SC	Ozone	Moderate	50
Chattanooga, TN-GA-AL	PM2.5	Nonattainment	100
Chicago-Gary-Lake County, IL-IN	Ozone	Moderate	50
Chicago-Gary-Lake County, IL-IN	PM2.5	Nonattainment	100
Chico, CA	Ozone	Former Subpart 1	50
Chico, CA	PM2.5	Nonattainment	100
Cincinnati-Hamilton, OH-KY-IN	Ozone	Former Subpart 1	50
Cincinnati-Hamilton, OH-KY-IN	PM2.5	Nonattainment	100
Clarksville-Hopkinsville, TN-KY	Ozone	Maintenance	100
Clearfield and Indiana Counties, PA	Ozone	Maintenance	100
Cleveland-Akron-Lorain, OH	Ozone	Maintenance	100

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Cleveland-Akron-Lorain, OH	PM2.5	Nonattainment	100
Columbus, OH	Ozone	Maintenance	100
Columbus, OH	PM2.5	Nonattainment	100
Dallas-Fort Worth, TX	Ozone	Moderate	50
Dayton-Springfield, OH	Ozone	Maintenance	100
Dayton-Springfield, OH	PM2.5	Nonattainment	100
Denver-Boulder-Greeley-Fort Collins-Loveland, CO	Ozone	Former Subpart 1	50
Detroit-Ann Arbor, MI	Ozone	Maintenance	100
Detroit-Ann Arbor, MI	PM2.5	Nonattainment	100
Door County, WI	Ozone	Former Subpart 1	50
Dukes County, MA	Ozone	Marginal	50
Erie, PA	Ozone	Maintenance	100
Essex County (Whiteface Mountain), NY	Ozone	Former Subpart 1	50
Evansville, IN	Ozone	Maintenance	100
Evansville, IN	PM2.5	Nonattainment	100
Fairbanks, AK	PM2.5	Nonattainment	100
Flint, MI	Ozone	Maintenance	100
Fort Wayne, IN	Ozone	Maintenance	100
Franklin County, PA	Ozone	Maintenance	100
Fredericksburg, VA	Ozone	Maintenance	100
Grand Rapids, MI	Ozone	Maintenance	100
Greater Connecticut, CT	Ozone	Moderate	50
Greene County, IN	Ozone	Maintenance	100
Greene County, PA	Ozone	Maintenance	100
Greensboro-Winston Salem-High Point, NC	Ozone	Marginal	50
Greensboro-Winston Salem-High Point, NC	PM2.5	Nonattainment	100
Hancock-Knox-Lincoln-Waldo Counties, ME	Ozone	Maintenance	100
Harrisburg-Lebanon-Carlisle, PA	Ozone	Maintenance	100
Harrisburg-Lebanon-Carlisle, PA	PM2.5	Nonattainment	100
Haywood and Swain Counties (Great Smoky Mountain National Park), NC	Ozone	Maintenance	100
Hickory-Morgantown-Lenoir, NC	PM2.5	Nonattainment	100
Houston-Galveston-Brazoria, TX	Ozone	Severe	25
Huntington-Ashland, WV-KY-OH	PM2.5	Nonattainment	100
Huntington-Ashland, WV-KY	Ozone	Maintenance	100
Huron County, MI	Ozone	Maintenance	100

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Imperial County, CA	Ozone	Moderate	50
Imperial County, CA	PM2.5	Nonattainment	100
Indianapolis, IN	Ozone	Maintenance	100
Indianapolis, IN	PM2.5	Nonattainment	100
Jackson County, IN	Ozone	Maintenance	100
Jamestown, NY	Ozone	Former Subpart 1	50
Jefferson County, NY	Ozone	Moderate	50
Johnstown, PA	Ozone	Maintenance	100
Johnstown, PA	PM2.5	Nonattainment	100
Kalamazoo-Battle Creek, MI	Ozone	Maintenance	100
Kansas City, MO-KS	Ozone	Maintenance	N/A
Kent and Queen Anne's Counties, MD	Ozone	Maintenance	100
Kern County (Eastern Kern), CA	Ozone	Former Subpart 1	50
Kewaunee County, WI	Ozone	Maintenance	100
Klamath Falls, OR	PM2.5	Nonattainment	100
Knoxville, TN	Ozone	Former Subpart 1	50
Knoxville, TN	PM2.5	Nonattainment	100
Lancaster, PA	Ozone	Maintenance	100
Lancaster, PA	PM2.5	Nonattainment	100
Lansing-East Lansing, MI	Ozone	Maintenance	100
Las Vegas, NV	Ozone	Former Subpart 1	50
Libby, MT	PM2.5	Nonattainment	100
Liberty-Clairton, PA	PM2.5	Nonattainment	100
Lima, OH	Ozone	Maintenance	100
Logan, UT-ID	PM2.5	Nonattainment	100
Los Angeles South Coast Air Basin, CA	Ozone	Extreme	10
Los Angeles South Coast Air Basin, CA	PM2.5	Nonattainment	100
Los Angeles-San Bernardino Counties (western Mohave), CA	Ozone	Moderate	50
Louisville, KY-IN	Ozone	Maintenance	100
Louisville, KY-IN	PM2.5	Nonattainment	100
Macon, GA	Ozone	Maintenance	100
Macon, GA	PM2.5	Nonattainment	100
Madison and Page Counties (Shenandoah NP), VA	Ozone	Maintenance	100
Manitowoc County, WI	Ozone	Former Subpart 1	50
Mariposa and Tuolumne Counties (Southern Mountain), CA	Ozone	Former Subpart 1	50
Martinsburg, WV-Hagerstown, MD	PM2.5	Nonattainment	100

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Mason County, MI	Ozone	Maintenance	100
Memphis, TN-AR	Ozone	Maintenance	100
Milwaukee-Racine, WI	Ozone	Moderate	50
Milwaukee-Racine, WI	PM2.5	Nonattainment	100
Morongo Band of Mission Indians, CA	Ozone	Serious	50
Muncie, IN	Ozone	Maintenance	100
Murray County (Chattahoochee NF), GA	Ozone	Maintenance	100
Muskegon, MI	Ozone	Maintenance	100
Nashville, TN	Ozone	Former Subpart 1	50
Nevada County (western part), CA	Ozone	Former Subpart 1	50
New York-N. New Jersey-Long Island, NY-NJ-CT	PM2.5	Nonattainment	100
New York-N. New Jersey-Long Island, NY-NJ-CT	Ozone	Moderate	50
Nogales, AZ	PM2.5	Nonattainment	100
Norfolk-Virginia Beach-Newport News, VA	Ozone	Maintenance	100
Oakridge, OR	PM2.5	Nonattainment	100
Parkersburg-Marietta, WV-OH	Ozone	Maintenance	100
Parkersburg-Marietta, WV-OH	PM2.5	Nonattainment	100
Pechanga Band of Luiseno Mission Indians of the Pechanga Reservation, CA	Ozone	Moderate	100
Philadelphia-Wilmington, PA-NY-DE	PM2.5	Nonattainment	100
Philadelphia-Wilmington-Atlantic City, PA-NY-MD-DE	Ozone	Moderate	50
Phoenix-Mesa, AZ	Ozone	Former Subpart 1	50
Pittsburgh-Beaver Valley, PA	Ozone	Former Subpart 1	50
Pittsburgh-Beaver Valley, PA	PM2.5	Nonattainment	100
Portland, ME	Ozone	Maintenance	100
Poughkeepsie, NY	Ozone	Moderate	50
Providence (entire State), RI	Ozone	Moderate	50
Provo, UT	PM2.5	Nonattainment	100
Raleigh-Durham-Chapel Hill, NC	Ozone	Maintenance	100
Reading, PA	Ozone	Maintenance	100
Reading, PA	PM2.5	Nonattainment	100
Richmond-Petersburg, VA	Ozone	Maintenance	100
Riverside County (Coachella Valley), CA	Ozone	Severe	25
Roanoke, VA	Ozone	Former Subpart 1	50
Rochester, NY	Ozone	Former Subpart 1	50
Rocky Mount, NC	Ozone	Maintenance	100

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Rome, GA	PM2.5	Nonattainment	100
Sacramento Metro, CA	Ozone	Severe	25
Sacramento Metro, CA	PM2.5	Nonattainment	100
Salt Lake City, UT	PM2.5	Nonattainment	100
San Diego, CA	Ozone	Former Subpart 1	50
San Francisco Bay Area, CA	Ozone	Marginal	50
San Francisco Bay Area, CA	PM2.5	Nonattainment	100
San Joaquin Valley, CA	Ozone	Extreme	10
San Joaquin Valley, CA	PM2.5	Nonattainment	100
San Luis Obispo (Eastern San Luis Obispo), CA	Ozone	Marginal	100
Scranton-Wilkes Barre, PA	Ozone	Maintenance	100
Seaford, DE	Ozone	Marginal	100
Seattle-Tacoma, WA	PM2.5	Nonattainment	100
Sheboygan, WI	Ozone	Moderate	50
South Bend-Elkhart, IN	Ozone	Maintenance	100
Springfield (western MA), MA	Ozone	Moderate	50
St. Louis, MO-IL	Ozone	Moderate	50
St. Louis, MO-IL	PM2.5	Nonattainment	100
State College, PA	Ozone	Maintenance	100
Steubenville-Weirton, OH-WV	Ozone	Maintenance	100
Steubenville-Weirton, OH-WV	PM2.5	Nonattainment	100
Sutter County (Sutter Buttes), CA	Ozone	Former Subpart 1	50
Terre Haute, IN	Ozone	Maintenance	100
Tioga County, PA	Ozone	Maintenance	100
Toledo, OH	Ozone	Maintenance	100
Tuscan Buttes, CA	Ozone	Marginal	100
Upper Green River Basin Area, WY	Ozone	Marginal	100
Ventura County, CA	Ozone	Serious	50
Washington County (Hagerstown), MD	Ozone	Former Subpart 1	50
Washington, DC-MD-VA	Ozone	Moderate	50
Washington, DC-MD-VA	PM2.5	Nonattainment	100
West Central Pinal County, AZ	PM2.5	Nonattainment	100
Wheeling, WV-OH	Ozone	Maintenance	100
Wheeling, WV-OH	PM2.5	Nonattainment	100
York, PA	Ozone	Maintenance	100
York, PA	PM2.5	Nonattainment	100

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Youngstown-Warren-Sharon, OH-PA	Ozone	Maintenance	100
Yuba City-Marysville, CA	PM2.5	Nonattainment	100

Notes:

[a] Pollutants for which the area is designated in nonattainment or maintenance as of 2013. For ozone nonattainment areas, the status given is the severity classification. "Former subpart 1" indicates an area that had been subject to nonattainment classification and implementation requirements under Title I, Part D, Subpart 1 of the Clean Air Act. Portions of Subpart 1 were struck down by court decision. As a result of that decision, former Subpart 1 areas are now subject to the classification and implementation requirements of Subpart 2.

[b] Emissions thresholds in tons/year. In ozone nonattainment areas the thresholds given are for the precursor pollutants VOC or NOx; in PM2.5 nonattainment areas the thresholds represent primary PM2.5. Source: 40 CFR § 51.853. These thresholds are provided for information only; a general conformity determination is not required for the Proposed Action.

Source: EPA 2013e.

N/A = conformity does not apply; NOx = nitrogen oxides; PM2.5 = particulate matter with a nominal aerodynamic diameter equal to or less than 2.5 microns; VOC = volatile organic compounds

4.1.2.6 Allocation of Upstream Emissions to Nonattainment Areas

Upstream emissions associated with the production and distribution of fuels used by motor vehicles are generated when fuel products are produced, processed, and transported. Upstream emissions are typically divided into four categories: feedstock recovery, feedstock transportation, fuel refining, and fuel transportation, storage, and distribution (TS&D). Feedstock recovery refers to the extraction or production of fuel feedstocks—the materials (e.g., crude oil) that are the main inputs to the refining process. In the case of petroleum, this is the stage of crude-oil extraction. During the next stage, feedstock transportation, crude oil or other feedstocks are shipped to fuel refineries. Fuel refining refers to the processing of crude oil into gasoline and diesel fuel. TS&D refers to the movement of gasoline and diesel from refineries to bulk terminals, storage at bulk terminals, and transportation of fuel from bulk terminals to retail outlets.[18] Emissions of pollutants at each stage are associated with expenditure of energy and with leakage or spillage and evaporation of fuel products.

NHTSA has allocated upstream emissions to individual nonattainment areas to provide additional information in its regional air quality analysis to the decisionmaker and the public, consistent with previous CAFE EISs and the Phase 1 HD Fuel Efficiency Improvement Program EIS. As noted below, NHTSA made a number of important assumptions for this analysis due to uncertainty over the accuracy of the allocation of upstream emissions. To analyze the impacts of the alternatives on individual nonattainment areas, NHTSA allocated emissions reductions to geographic areas according to the following methodology:

- **Feedstock recovery**. NHTSA assumed that little to no extraction of crude oil occurs in nonattainment areas. Of the top 50 highest producing oil fields in the United States, only 10 are in

[18] Emissions that occur while vehicles are being refueled at retail stations are included in estimates of emissions from vehicle operation.

nonattainment areas. These 10 fields account for 15 percent of domestic production, or 3 percent of total crude-oil imports plus domestic production in 2009 (EIA 2009, 2014b, 2014c). Therefore, because relatively little extraction occurs in nonattainment areas, NHTSA did not account for emissions reductions from crude oil feedstock recovery in nonattainment areas.

NHTSA assumed that little to no extraction of natural gas occurs in nonattainment areas. Of the top 50 highest producing natural gas fields in the United States, 8 are in nonattainment areas. These 8 fields account for 6 percent of total natural gas imports plus domestic gross withdrawals in 2009 (EIA 2009, 2014d, 2014e). Therefore, because relatively little extraction occurs in nonattainment areas, NHTSA did not account for emissions reductions from natural gas feedstock recovery in nonattainment areas.

- **Feedstock transportation**. NHTSA assumed that little to no crude oil is transported through nonattainment areas. Most refineries are outside or on the outskirts of urban areas. Crude oil is typically transported hundreds of miles from extraction points and ports to reach refineries. Most transportation is by ocean tanker and pipeline. Probably only a very small proportion of criteria pollutants emitted in the transport of crude oil occur in nonattainment areas. Therefore, NHTSA did not consider emissions reductions from feedstock transportation within nonattainment areas.

Because NHTSA did not account for emissions changes from the first two upstream stages, the assumptions produce conservative estimates of emissions reductions in nonattainment areas (i.e., the estimates slightly underestimate the emissions reductions associated with lower fuel production and use).

- **Fuel refining.** Fuel refining is the largest source of upstream emissions of criteria pollutants. Depending on the specific fuel and pollutant, fuel refining accounts for between 9 percent and 86 percent of all upstream emissions per unit of fuel produced and distributed (based on GREET version 1.8c). NHTSA used projected emissions data from the EPA 2011-based air quality modeling platform (EPA 2014d) to allocate reductions in nationwide total emissions from fuel refining to individual nonattainment areas. These EPA data were for 2018, the most representative year available in the EPA dataset. The EPA NEI includes estimates of emissions of criteria and toxic pollutants by county and by source category. Because fuel refining represents a separate source category in the NEI, it is possible to estimate the share of nationwide emissions from fuel refining that occurs within each nonattainment area. This analysis assumes that the share of fuel-refining emissions allocated to each nonattainment area does not change over time, which in effect means that fuel-refining emissions are assumed to change uniformly across all refineries nationwide as a result of each alternative.
- **TS&D**. NHTSA used data from the 2011-based EPA modeling platform (EPA 2014e) to allocate TS&D emissions to nonattainment areas in the same way as for fuel-refining emissions. NHTSA's analysis assumes that the share of TS&D emissions allocated to each nonattainment area does not change over time, and that TS&D emissions will change uniformly nationwide as a result of the alternatives.

4.1.2.7 Health Outcomes and Monetized Benefits

4.1.2.7.1 Overview

This section describes NHTSA's approach to providing quantitative estimates of adverse health effects of conventional air pollutants associated with each alternative. In this analysis, NHTSA quantified and monetized the impacts on human health anticipated to result from the changes in pollutant emissions and related changes in human exposure to air pollutants under each alternative. NHTSA evaluated the

changes to several health outcomes and the monetized benefits associated with avoided health outcomes.

Table 4.1.2-2 lists the health outcomes NHTSA quantified and monetized. This methodology estimates the health impacts of each alternative for each analysis year, expressed as the number of additional or avoided adverse health outcomes per year.

Health and monetary outcomes are calculated from factors for each primary pollutant (NO_x, directly emitted PM2.5 and SO_2), expressed as adverse health outcomes avoided or monetized health benefits gained per ton of reduced emissions. The general approach to calculating the health outcomes associated with each alternative is to multiply these factors by the estimated annual reduction in emissions of that pollutant, and to sum the results of these calculations for all pollutants. This calculation provides the total health impacts and monetized health benefits that would be achieved under each alternative.

Table 4.1.2-2. Human Health and Welfare Effects of PM2.5

Effects Quantified and Monetized	Effects Excluded from Quantification or Monetization [a]
Adult premature mortality	Chronic bronchitis (age >26)
Infant mortality	Emergency room visits for cardiovascular effects
Acute bronchitis (age 8-12)	Strokes and cerebrovascular disease (age 50–79)
Hospital admissions: respiratory (all ages) and cardiovascular (age >26)	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)
Emergency room visits for asthma	Cardiovascular effects other than those listed
Nonfatal heart attacks (age >18)	Reproductive and developmental effects (e.g., low birth weight, pre-term births)
Lower (age 7–14) and upper (age 9–11) respiratory symptoms	Cancer, mutagenicity, and genotoxicity effects
Minor restricted-activity days (age 18–65)	
Lost work days (age 18–65)	
Asthma exacerbations (asthmatics age 6–18)	

Notes:

[a] EPA excluded these effects because of insufficient confidence in available data or methods, or because current evidence is only suggestive of causality or there are other significant concerns over the strength of the association.

Source: EPA 2013f. *See* this source for more information related to the affected ages included in the analysis.

EPA = U.S. Environmental Protection Agency

In calculating the health impacts and monetized health benefits of emissions reductions, NHTSA estimated only the PM2.5-related human health impacts expected to result from reduced population exposure to atmospheric concentrations of PM2.5. Two other pollutants—NO_x and SO_2—are included in the analysis as precursor emissions that contribute to PM2.5 not emitted directly from a source, but instead formed by chemical reactions in the atmosphere (secondary PM2.5). As discussed further in Section 4.1.2.7.2, reductions in NO_x and VOC emissions would also reduce ozone formation and the health effects associated with ozone exposure, but there are no benefit-per-ton estimates for NO_x and VOCs because of the complexity of the atmospheric air chemistry and non-linearities associated with ozone formation. This analysis does not include any reductions in health impacts resulting from lower

population exposure to other criteria air pollutants and air toxics because there are not enough data available to quantify these effects.

4.1.2.7.2 Monetized Health Impacts

The benefit-per-ton factors represent the total monetized human health benefits due to a suite of monetized PM-related health impacts for each ton of emissions reduced. The factors are specific to an individual pollutant and source. The PM2.5 benefit-per-ton estimates apply to directly emitted PM2.5 or its precursors (NO_x and SO_2). NHTSA followed the benefit-per-ton technique used in EPA's PM2.5 NAAQS Regulatory Impact Analysis (RIA) (EPA 2013c), Ozone NAAQS RIA (EPA 2010a), Portland Cement National Emission Standards for Hazardous Air Pollutants RIA (EPA 2010b), and NO_2 NAAQS RIA (EPA 2010c), and most recently updated in EPA's Technical Support Document *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2013f). Updates from the 2006 PM NAAQS RIA in the 2012 PM2.5 NAAQS RIA include no longer assuming a concentration threshold in the concentration-response function for the PM2.5-related health effects; using benefits derived from two major cohort studies of PM2.5 and mortality as the core benefits estimates; and baseline incidence rates for hospital admissions, emergency department visits, and asthma prevalence rates. Revised health endpoints, sensitivity analyses, new morbidity studies, and an updated median wage data were also included.

Table 4.1.2-2 lists the quantified PM2.5-related benefits captured in those benefit-per-ton estimates, and potential PM2.5-related benefits that were not quantified in this analysis. The benefits estimates use the concentration-response functions[19] as reported in the epidemiology literature. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult EPA's Technical Support Document *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2013f). Readers can also consult Fann et al. (2009) for a detailed description of the benefit-per-ton methodology.[20]

As described in the documentation cited above for the benefit-per-ton estimates, EPA developed national per-ton estimates for selected pollutants emitted through stationary and mobile activity. Because the per-ton values vary slightly between the two categories, the total health and monetized health impacts were derived by multiplying the stationary per-ton estimates by total upstream emissions, and the mobile per-ton estimates by total mobile emissions. NHTSA's estimate of PM2.5 benefits is, therefore, based on the total direct PM2.5 and PM2.5-related precursor emissions controlled by sector and multiplied by this per-ton value.

PM-related mortality provides most of the monetized value in each benefit-per-ton estimate. EPA calculated the premature mortality-related effect coefficients that underlie the benefits-per-ton

[19] Concentration-response functions measure the relationship between exposure to pollution as a cause and specific outcomes as an effect (e.g., the incremental number of hospitalizations that would result from exposure of a population to a specified concentration of an air pollutant over a specified period).

[20] Note that since the publication of Fann et al. (2009), EPA has made two significant changes to its benefits methods: (1) EPA no longer assumes that there is a threshold in PM-related models of health impacts and (2) EPA has revised its value of a statistical life (VSL) to equal $6.3 million (in year 2000 dollars), or $8.4 million (in year 2012 dollars), up from an estimate of $5.5 million (in year 2000 dollars) used in Fann et al. (2009). (VSL refers to the aggregate estimated value of reducing small risks across a large number of people. It is based on how people themselves would value reducing these risks.) NHTSA's analysis follows this EPA method, except that NHTSA uses DOT's estimate of the value of VSL as discussed in this section (DOT 2014).

estimates from epidemiology studies that examined two large population cohorts—the American Cancer Society cohort (Krewski et al. 2009) and the Harvard Six Cities cohort (Lepeule et al. 2012). These are logical choices for anchor points when presenting PM-related benefits because, although the benefit-per-ton results vary between the two studies, EPA considers both studies to be equal in terms of strengths and weaknesses and the quality of results. According to EPA, both studies should be used to generate benefits estimates (EPA 2013f). Throughout the discussion of mortality in this section, the mortality rates calculated from each of these studies are presented side by side.

For both studies, the benefits of mortality reductions do not occur in the year of analysis. Instead, EPA's methodology assumes that there is a cessation lag—that is, the benefits are distributed across 20 years following the year of exposure (the emissions analysis year). Because of this, the monetized value of the reduced mortality depends on the discount rate applied to future-year benefits from the cessation lag. To account for this factor, the monetized benefits of reduced mortality are presented using a 3 percent discount rate and a 7 percent discount rate. Because the 7 percent discount rate places less present value on future-year benefits than the 3 percent discount rate, the present-year benefit of reductions is approximately 10 percent smaller under the 7 percent discount rate than under the 3 percent discount rate.

The benefits-per-ton estimates used in this analysis are based on the above mortality health outcome factors, combined with data on the monetized value of each health outcome. These monetized values are expressed through several metrics; premature mortality is monetized using DOT's estimate of the value of statistical life (VSL) (DOT 2013). Morbidity impacts are measured either through willingness-to-pay or cost-of-illness measures that account for either desire to avoid the health outcome or actual medical costs and wage lost associated with a specific case.

NHTSA adjusted EPA's benefit-per-ton values to change the value of VSL from the EPA VSL of $8.4 million in 2012 dollars to the DOT VSL of $9.1 million (in 2012 dollars).[21] Note that because the benefits-per-ton data combine mortality and morbidity benefits, the adjustment for DOT VSL is applied to both mortality and morbidity components of the data. Because VSL represents only mortality, this adjustment likely results in the analysis underestimating the total benefits per ton. However, because mortality accounts for most of total monetized health benefits, any underestimation is likely to be small.

Table 4.1.2-3 lists the dollar-per-ton estimates used in this analysis.[22] Table 4.1.2-4 lists the valuation metrics for the mortality and morbidity endpoints.

[21] Departmental guidance on valuing reduction of fatalities was first published in 1993, and subsequently updated in 2008 on the basis of later research. Since then, DOT has updated this VSL to 2013 values in accordance with changes in prices and incomes over the past several years. However, for this rulemaking DOT and EPA have agreed to express monetized values in terms of 2012 dollars.

[22] The VSL derived by DOT and used for this EIS is $9.1 million in 2012 dollars. This value differs from the VSL adopted by EPA in the 2014 Update of the Guidelines for Preparing Economic Analyses (EPA 2014f) and estimated at $7.9 million in 2008 dollars. The discrepancy between these estimates is not unexpected, because no single dollar value has been accepted in the academic community or across the Federal Government.

Table 4.1.2-3. Benefit-per-ton Values (in 2012 dollars) Derived for PM-related Mortality and Morbidity, Adjusted to Reflect DOT's Value of Statistical Life[a]

Year[b]	Upstream Emissions (Data for Refineries Sector)			Downstream Emissions (Data for On-Road Sources Sector)		
	Direct PM2.5	SO_2	NO_X	Direct PM2.5	SO_2	NO_X
3-Percent Discount Rate						
Mortality[c] and Morbidity – Krewski et al. (2009)						
2018	$365,000	$78,000	$8,000	$422,000	$23,000	$9,000
2025	$422,000	$90,000	$9,000	$479,000	$26,000	$10,000
2035	$495,000	$106,000	$10,000	$564,000	$32,000	$11,000
2050	$495,000	$106,000	$10,000	$564,000	$32,000	$11,000
Mortality[c] and Morbidity – Lepeule et al. (2012)						
2018	$833,000	$177,000	$18,000	$952,000	$51,000	$19,000
2025	$947,000	$205,000	$19,000	$1,084,000	$59,000	$22,000
2035	$1,104,000	$236,000	$23,000	$1,229,000	$72,000	$25,000
2050	$1,104,000	$236,000	$23,000	$1,229,000	$72,000	$25,000
7-Percent Discount Rate						
Mortality[c] and Morbidity – Krewski et al. (2009)						
2018	$331,000	$71,000	$7,000	$382,000	$21,000	$8,000
2025	$376,000	$81,000	$8,000	$433,000	$24,000	$9,000
2035	$443,000	$95,000	$9,000	$505,000	$29,000	$10,000
2050	$443,000	$95,000	$9,000	$505,000	$29,000	$10,000
Mortality[c] and Morbidity – Lepeule et al. (2012)						
2018	$753,000	$154,000	$15,000	$861,000	$46,000	$18,000
2025	$855,000	$183,000	$18,000	$981,000	$54,000	$19,000
2035	$994,000	$213,000	$21,000	$1,144,000	$64,000	$23,000
2050	$994,000	$213,000	$21,000	$1,144,000	$64,000	$23,000

Notes:

[a] The benefits-per-ton estimates in this table are based on EPA estimates of premature mortality by Krewski et al. (2009) and Lepeule et al. (2012), and a suite of morbidity endpoints (*see* Table 4.1.2-2). Benefits for two sectors (on-road mobile source and refineries) of the 17 sectors analyzed in EPA 2013f.

[b] Benefit-per-ton values were estimated for 2016, 2020, 2025, and 2030. For 2018 and 2035, values were either interpolated or extrapolated based on the growth between 2018 and 2030. For 2050, values were held constant from 2035 values because of the high level of uncertainty in projections to 2060. All values have been rounded.

[c] For age under 25 or age over 30.

Source: EPA 2013f.

NO_x = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide

Table 4.1.2-4. Valuation Metrics for Mortality and Morbidity Endpoints (in 2012 dollars)

Health Outcome	Valuation Method	Valuation[a]
Premature Mortality		
Premature Mortality	DOT Mean VSL	$10,400,000
Chronic Illness		
Myocardial Infarctions, Nonfatal	Medical costs over 5 years; varies by age and discount rate.	Varies from $110,000 to $230,000, depending on age and discount rate
Hospital Admissions		
Respiratory, Age 65+	COI: Medical Costs + Wage Lost	$41,000
Chronic Lung Disease, Ages 18–64	COI: Medical Costs + Wage Lost	$24,000
Cardiovascular	COI: Medical Costs + Wage Lost (18–64) COI: Medical Costs + Wage Lost (65–99)	$48,000 $47,000
Emergency Room Visits		
Asthma	COI: 2 Studies	$490
Other Health Endpoints		
Acute Bronchitis	WTP: 6 Day Illness, CV Studies	$530
Upper Respiratory Symptoms	WTP: 1 Day, CV Studies	$37
Lower Respiratory Symptoms	WTP: 1 Day, CV Studies	$23
Asthma Exacerbation	WTP: Bad Asthma Day	$564
Work Loss Days	Median Daily Wage, County-Specific	Variable (U.S. Median = $170)
Minor Restricted Activity Days	WTP: 1 Day, CV Studies	$76

Notes:

[a] Central Estimate of Value Per Statistical Incidence. Table 5-9 in EPA 2013f presented VSLs for the year 1990, 2000, and 2020 income levels. The valuation presented in this table was interpolated for the year 2012 and are presented here in 2012 dollars. Dollar amounts for each valuation method were extracted by EPA from BenMAP and were presented in 2010 dollars in EPA 2013f.

Source: EPA 2013f.

COI = cost of illness; CV = contingent valuation; OT = Department of Transportation; VSL = value of statistical life; WTP = willingness to pay

The benefit-per-ton estimates are subject to several assumptions and uncertainties, as follows.

- The benefit-per-ton estimates used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines, and incomes. These projections introduce some uncertainties to the benefit-per-ton estimates.
- These estimates do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates (PM2.5). Emissions changes and benefit-per-ton estimates alone are not a precise indication of local or regional air quality and health impacts because there could be localized impacts associated with the Proposed Action. Because the atmospheric chemistry related to ambient concentrations of PM2.5, ozone, and air toxics is very complex, full-scale photochemical air quality modeling is necessary to control for local variability. Full-scale photochemical modeling provides the needed spatial and temporal detail to more

completely and accurately estimate changes in ambient levels of these pollutants and their associated impacts on human health and welfare. This modeling provides insight into the uncertainties associated with the use of benefit-per-ton estimates. At this time, NHTSA intends to conduct a photochemical modeling analysis for the Final EIS using the same methodology as in the CAFE Final EISs and the MDHD Phase 1 Final EIS.

- NHTSA assumed that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because PM2.5 produced via transported precursors emitted from stationary sources might differ significantly from direct PM2.5 released from diesel engines and other industrial sources. However, there are no clear scientific grounds to support estimating differential effects by particle type.
- NHTSA assumed that the health impact (concentration-response) function for fine particles is linear within the range of ambient concentrations under consideration. Therefore, the estimates include health benefits from reducing fine particles in areas with varied concentrations of PM2.5, including regions that are in attainment with the fine-particle standard and those that do not meet the standard, down to the lowest modeled concentrations.
- Other uncertainties associated with the health impact functions include the following: within-study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across-study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings, and in some cases the differences are substantial); the application of concentration-response functions nationwide (does not account for any relationship between region and health effect, to the extent that there is such a relationship); and extrapolation of impact functions across population (NHTSA assumed that certain health impact functions applied to age ranges broader than those considered in the original epidemiological study). These uncertainties could under- or overestimate benefits.
- There are several health-benefits categories NHTSA was unable to quantify due to limitations associated with using benefit-per-ton estimates, several of which could be substantial. Because NO_x and VOCs are also precursors to ozone, reductions in NO_x and VOC emissions would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, there are no benefit-per-ton estimates because of the complexity of the atmospheric air chemistry and non-linearities associated with ozone formation. The PM-related benefit-per-ton estimates also do not include any human welfare or ecological benefits due to limitations on the availability of data to quantify these effects of pollutant emissions.

The RIA for the 2012 PM2.5 NAAQS (EPA 2013c) provides more information about the overall uncertainty in the estimates of the benefits of reducing PM2.5 emissions.

4.1.2.7.3 Quantified Health Impacts

Table 4.1.2-5 lists the incidence-per-ton estimates for select PM-related health impacts – mortality and four major morbidity outcomes (derived by the same process as described above for the dollar-per-ton estimates). For the analysis of direct and indirect impacts (*see* Section 4.2.1) and cumulative impacts (*see* Section 4.2.2), NHTSA used the values for 2018, 2025, 2035, and 2030 (*see* Section 4.1.2.3). NHTSA applied the values for 2030 to estimate impacts in 2035 and 2050.

Table 4.1.2-5. Incidence-per-ton Values for Health Outcomes

Outcome and Year[a]	Upstream Emissions (Data for Refineries Sector)			Downstream Emissions (Data for On-Road Sources Sector)		
	Direct PM2.5	SO_2	NO_X	Direct PM2.5	SO_2	NO_X
Premature Mortality – Krewski et al. (2009)						
2016	0.027000	0.00770	0.00076	0.042000	0.00220	0.00085
2018	0.032500	0.00785	0.00078	0.042500	0.00225	0.00086
2020	0.038000	0.00800	0.00079	0.043000	0.00230	0.00087
2025	0.040000	0.00860	0.00085	0.047000	0.00260	0.00093
2030	0.044000	0.00950	0.00092	0.051000	0.00280	0.00100
Premature Mortality – Lepeule et al. (2012)						
2016	0.062000	0.01700	0.00170	0.094000	0.00500	0.00190
2018	0.073500	0.01750	0.00175	0.096000	0.00515	0.00195
2020	0.085000	0.01800	0.00180	0.098000	0.00530	0.00200
2025	0.091000	0.02000	0.00190	0.110000	0.00580	0.00210
2030	0.099000	0.02100	0.00210	0.110000	0.00640	0.00230
Acute Bronchitis						
2016	0.042000	0.01300	0.00130	0.067000	0.00400	0.00140
2018	0.052000	0.01300	0.00130	0.068000	0.00405	0.00140
2020	0.062000	0.01300	0.00130	0.069000	0.00410	0.00140
2025	0.065000	0.01400	0.00140	0.072000	0.00440	0.001400.00140
2030	0.066000	0.01400	0.00140	0.075000	0.00460	0.00150
Work Loss Days						
2016	3.80000	1.10000	0.11000	5.90000	0.32000	0.12000
2018	4.55000	1.10000	0.11000	6.00000	0.33000	0.12000
2020	5.30000	1.10000	0.11000	6.10000	0.34000	0.12000
2025	5.30000	1.20000	0.11000	6.20000	0.35000	0.12000
2030	5.40000	1.20000	0.12000	6.40000	0.36000	0.12000
Emergency Room Visits – Respiratory						
2016	0.015000	0.00410	0.00042	0.024000	0.00110	0.00049
2018	0.017500	0.00415	0.00043	0.024500	0.00115	0.00050
2020	0.020000	0.00420	0.00043	0.025000	0.00120	0.00050
2025	0.020000	0.00430	0.00044	0.026000	0.00120	0.00051
2030	0.021000	0.00450	0.00046	0.026000	0.00130	0.00053

Notes:

[a] EPA estimated benefit-per-ton values for 2016, 2020, 2025, and 2030. For 2018, values were interpolated from trends shown in EPA 2013f. For 2035 and 2050 the EPA values for 2030 were used.

Source: EPA 2013f.

EPA = U.S. Environmental Protection Agency; NO_X = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide

4.2 Environmental Consequences

4.2.1 Direct and Indirect Impacts

4.2.1.1 Results of the Analysis

As discussed in Section 4.1, most criteria pollutant emissions from vehicles have been declining since 1970 as a result of EPA's emissions regulations under the CAA. EPA projects that these emissions will continue to decline. However, as future trends show, vehicle travel is having a decreasing impact on emissions as a result of stricter EPA standards for vehicle emissions and the chemical composition of fuels, even with additional growth in VMT (Smith 2002, EPA 2012c). This general trend will continue, to a greater or lesser degree, with implementation of any of the alternatives.

The analysis in this section shows that the action alternatives result in different levels of emissions from HD vehicles when measured against projected trends under the No Action Alternative. These reductions or increases in emissions vary by pollutant, calendar year, and action alternative. The more stringent action alternatives generally would result in greater emissions reductions compared to the No Action Alternative.

This section examines the direct and indirect impacts on air quality associated with the action alternatives.[23] Section 4.2.2 examines cumulative air quality impacts of the action alternatives.[24] Using the assumptions discussed in Section 2.3, this chapter presents direct and indirect impacts and cumulative air quality impacts to show a complete range of results.

The tables and figures in Section 4.2.1 and its subsections present the projected direct and indirect impacts of the action alternatives on air quality. Following the comparative overview in this section, Sections 4.2.1.2 through 4.2.1.5 describe the results of the analysis of emissions under Alternatives 1 through 5 in more detail.

4.2.1.1.1 Criteria Pollutants Overview

Table 4.2.1-1 summarizes the total upstream and downstream[25] national emissions from HD vehicles by alternative for each of the criteria pollutants and analysis years. Figure 4.2.1-1 illustrates this information for 2035, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the Proposed Action.

---

[23] As explained in Chapter 2, the analysis of direct and indirect impacts compares action alternatives with a No Action Alternative that generally reflects a small forecast increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, due to market-based incentives for improving fuel efficiency. By including these market-based improvements in the No Action Alternative, this analysis attempts to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the proposed rule, and not attributable to reasonably foreseeable future actions by manufacturers.

[24] As explained in Chapter 2, the cumulative impacts analysis compares the same action alternatives with a No Action Alternative that generally assumes no increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond (i.e., no increase beyond the 2014-2018 Phase 1 HD standards). In other words, this baseline does not take into account market-based incentives for improving fuel efficiency. By comparing the action alternatives to this baseline, the cumulative impacts analysis reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 and the direct and indirect impacts of Phase 2 HD standards associated with each action alternative.

[25] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

Table 4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	2,022,153	2,022,049	2,022,017	2,022,032	2,022,015
2025	1,613,987	1,593,855	1,584,461	1,583,774	1,574,006
2035	1,386,395	1,322,540	1,303,407	1,303,201	1,285,336
2050	1,557,183	1,465,076	1,439,871	1,440,064	1,417,090
Nitrogen oxides (NO_X)					
2018	2,185,443	2,184,866	2,184,735	2,184,710	2,184,542
2025	1,429,740	1,359,701	1,327,865	1,324,042	1,291,485
2035	1,128,951	910,303	837,790	835,135	774,765
2050	1,326,493	1,012,596	913,122	912,654	834,570
Particulate matter (PM2.5)					
2018	97,464	97,430	97,422	97,419	97,410
2025	60,109	59,964	59,741	59,475	59,158
2035	43,985	43,860	42,481	42,311	41,552
2050	51,317	51,269	49,155	49,117	48,101
Sulfur dioxide (SO_2)					
2018	121,098	120,924	120,871	120,853	120,806
2025	129,757	125,916	123,602	122,105	119,296
2035	141,640	131,283	121,936	120,982	114,928
2050	167,699	153,560	139,849	139,566	131,589
Volatile organic compounds (VOC)					
2018	342,799	342,620	342,568	342,552	342,504
2025	278,241	267,595	262,117	260,350	254,133
2035	260,507	227,885	211,836	210,765	198,496
2050	307,333	260,890	238,313	238,088	222,168

Figure 4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Direct and Indirect Impacts

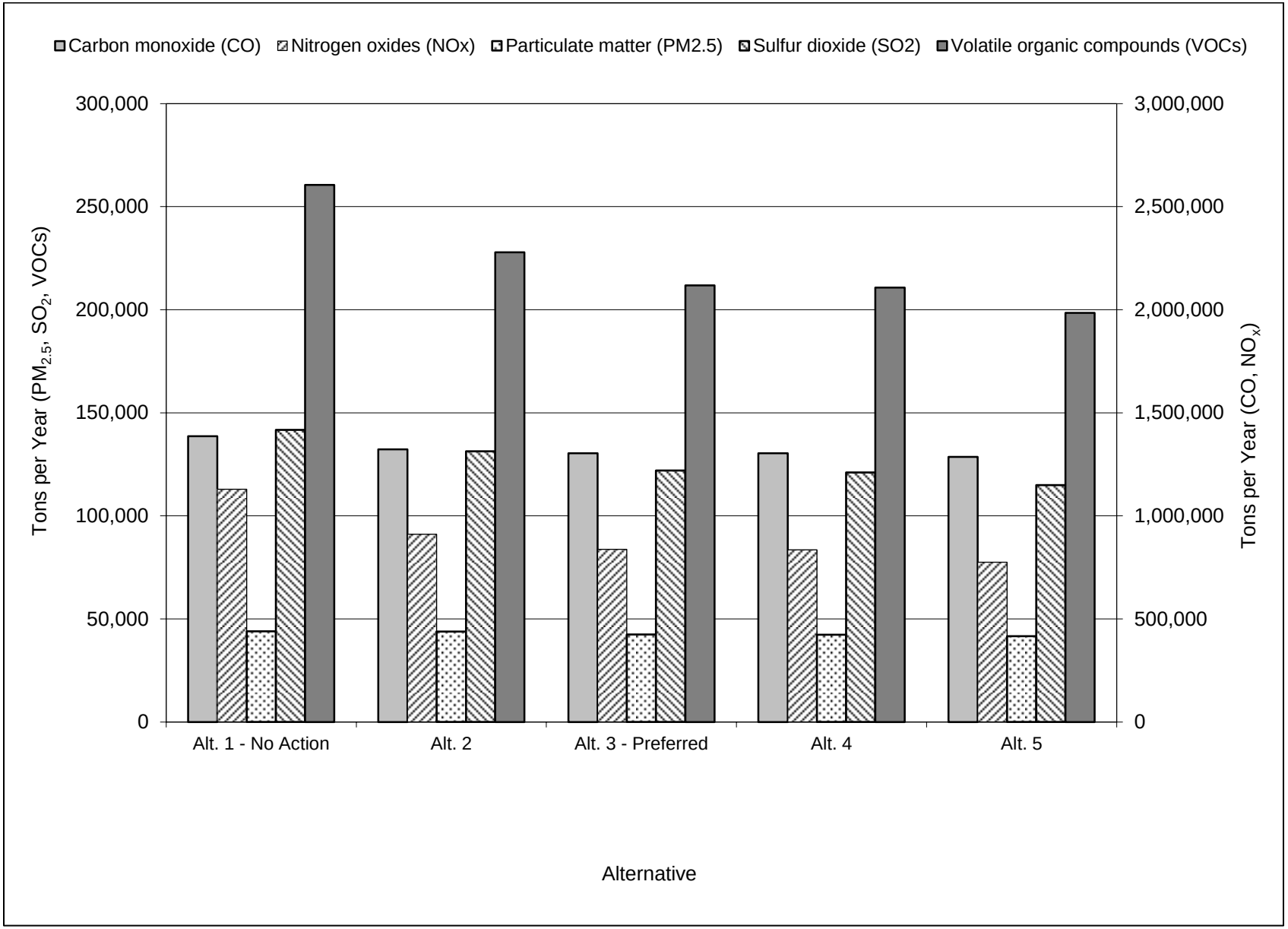


Figure 4.2.1-2 summarizes the changes over time in total national emissions of criteria pollutants from HD vehicles under the Preferred Alternative. Figures 4.2.1-1 and 4.2.1-2 show a consistent trend among the criteria pollutants. Emissions of CO, NO_x, PM2.5, and VOCs would decrease due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2035, but increase from 2035 to 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.1-1 and Figure 4.2.1-1). (Note that continued growth in VMT is projected to occur under all alternatives).

Emissions of SO_2 under all alternatives are predicted to increase from 2018 to 2050 because declines due to gains in new HD vehicle fuel efficiency are more than offset by continuing growth in VMT. The timing of the increases between 2018 and 2050 varies by alternative. EPA regulates vehicle SO_2 emissions by limiting the concentration of sulfur in fuel and has not established tailpipe emissions standards for SO_2. As a result, SO_2 emissions vary only with total fuel consumption. Under the No Action Alternative, which assumes neither NHTSA nor EPA promulgate Phase 2 standards (i.e., the No Action Alternative), total fuel consumption rises as VMT grows, and SO_2 emissions increase continuously from 2018 to 2050. Alternative 2 is not sufficiently stringent for fuel savings to offset VMT growth, so SO_2 emissions increase continuously from 2018 to 2050 under Alternative 2 as well. Under the Preferred Alternative and Alternative 4, SO_2 emissions increase from 2018 to 2025 but decrease by 2035 as the proportion of all vehicles that meets the Phase 2 standards increases, before emissions increase again by 2050 due to continued VMT growth. Alternative 5 is sufficiently stringent that fuel savings offset VMT growth even in the early years of Phase 2 implementation, and SO_2 emissions decrease continuously from 2018 to 2035 before increasing by 2050 due to continued VMT growth.

Total emissions are made up of six components, consisting of two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three vehicle classes covered by the proposed rule: Classes 2b–3 HD pickups and vans, Classes 3–8 vocational vehicles, and Classes 7–8 tractor-trailers. (Emissions associated with the tractor-trailer classes include effects of proposed trailer standards.) To show the relationship among these six components for criteria pollutants, Table 4.2.1-2 breaks down the total emissions of criteria pollutants by component for calendar year 2035.

Figure 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Direct and Indirect Impacts

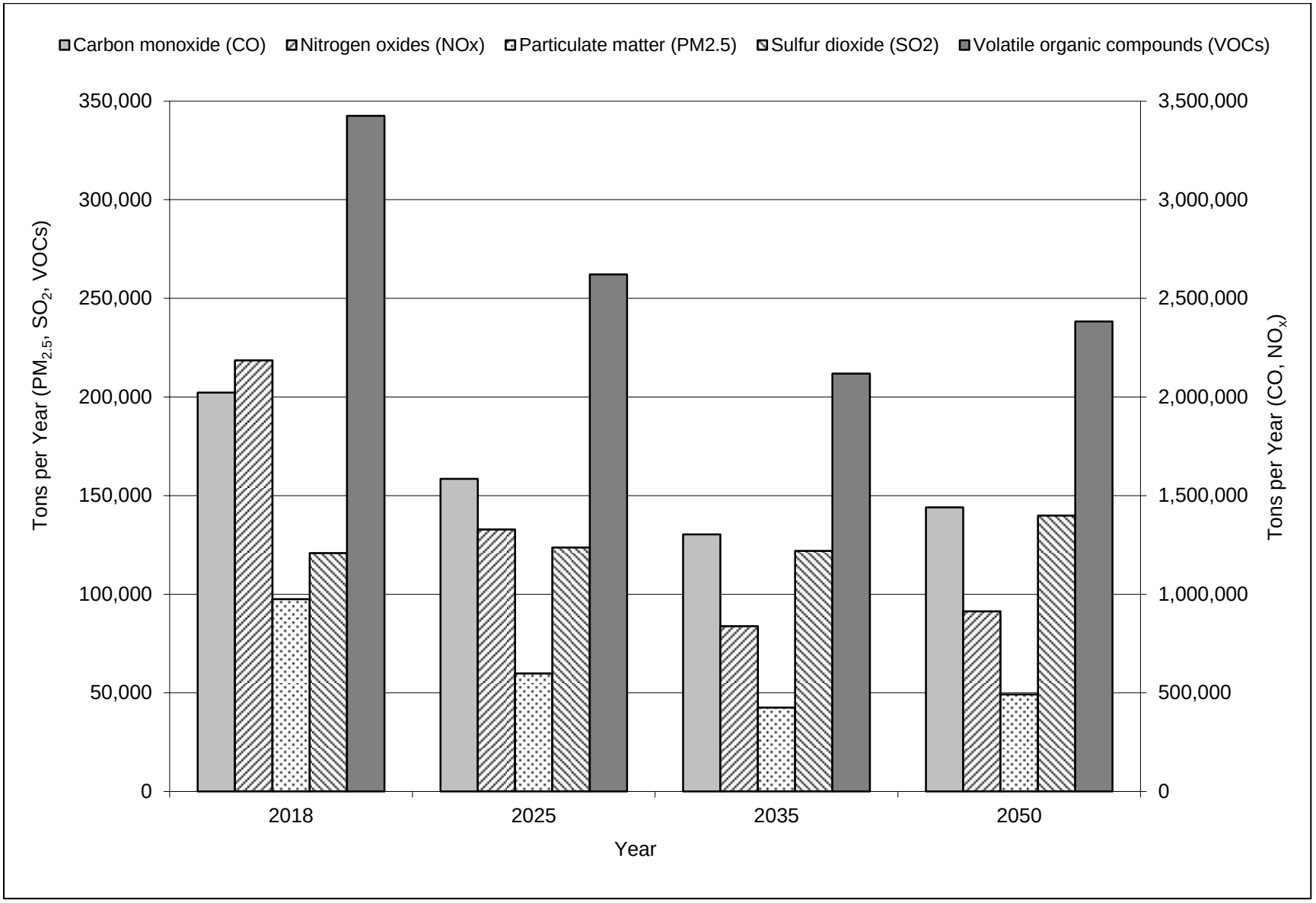


Table 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Direct and Indirect Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
Classes 2b–3 Work Trucks Tailpipe	327,665	329,060	330,615	331,042	331,588
Classes 2b–3 Work Trucks Upstream	10,262	9,708	9,177	9,046	8,869
Classes 3–8 Vocational Vehicles Tailpipe	657,139	659,084	658,786	658,753	658,429
Classes 3–8 Vocational Vehicles Upstream	16,147	15,681	14,585	14,461	13,649
Classes 7–8 Combination Unit Tailpipe	316,936	256,028	241,305	241,257	226,898
Classes 7–8 Combination Unit Upstream	58,246	52,977	48,939	48,641	45,903
Total	1,386,395	1,322,54	1,303,407	1,303,20	1,285,33
Nitrogen oxides (NO_X)					
Classes 2b–3 Work Trucks Tailpipe	46,814	47,025	47,162	47,214	47,258
Classes 2b–3 Work Trucks Upstream	33,830	32,005	30,261	29,834	29,255
Classes 3–8 Vocational Vehicles Tailpipe	115,395	116,728	116,422	116,390	116,077
Classes 3–8 Vocational Vehicles Upstream	39,524	38,385	35,703	35,399	33,411
Classes 7–8 Combination Unit Tailpipe	751,086	546,728	488,679	487,463	436,619
Classes 7–8 Combination Unit Upstream	142,302	129,430	119,563	118,836	112,145
Total	1,128,951	910,303	837,790	835,135	774,765
Particulate matter (PM2.5)					
Classes 2b–3 Work Trucks Tailpipe	2,005	2,016	2,024	2,027	2,029
Classes 2b–3 Work Trucks Upstream	3,050	2,886	2,732	2,694	2,643
Classes 3–8 Vocational Vehicles Tailpipe	4,240	4,299	4,294	4,293	4,289
Classes 3–8 Vocational Vehicles Upstream	4,541	4,416	4,107	4,072	3,845
Classes 7–8 Combination Unit Tailpipe	14,692	16,185	16,337	16,318	16,565
Classes 7–8 Combination Unit Upstream	15,457	14,059	12,987	12,908	12,181
Total	43,985	43,860	42,481	42,311	41,552
Sulfur dioxide (SO_2)					
Classes 2b–3 Work Trucks Tailpipe	553	556	558	559	560
Classes 2b–3 Work Trucks Upstream	22,136	20,942	19,800	19,520	19,141
Classes 3–8 Vocational Vehicles Tailpipe	1,154	1,123	1,044	1,036	978
Classes 3–8 Vocational Vehicles Upstream	24,644	23,930	22,258	22,068	20,828
Classes 7–8 Combination Unit Tailpipe	3,873	3,527	3,261	3,241	3,060
Classes 7–8 Combination Unit Upstream	89,281	81,205	75,014	74,558	70,360

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Total	141,640	131,283	121,936	120,982	114,928
Volatile organic compounds (VOC)					
Classes 2b–3 Work Trucks Tailpipe	13,654	13,716	13,771	13,789	13,808
Classes 2b–3 Work Trucks Upstream	18,613	17,587	16,408	16,165	15,766
Classes 3–8 Vocational Vehicles Tailpipe	29,984	29,741	28,563	28,424	27,562
Classes 3–8 Vocational Vehicles Upstream	27,327	26,921	25,044	24,833	23,517
Classes 7–8 Combination Unit Tailpipe	132,724	105,171	95,949	95,648	87,734
Classes 7–8 Combination Unit Upstream	38,206	34,750	32,101	31,905	30,109
Total	260,507	227,885	211,836	210,765	198,496

Table 4.2.1-3 lists the net changes in nationwide criteria pollutant emissions from HD vehicles for each action alternative for each criteria pollutant and analysis year compared to the No Action Alternative in the same year. Figure 4.2.1-3 shows these changes in percentages for 2035. As a general trend, total emissions of each pollutant in a given year decrease from Alternative 2 through Alternative 5, as each successive alternative becomes more stringent. In Table 4.2.1-3, this trend shows as a growing difference between the No Action Alternative and each action alternative from Alternative 2 through Alternative 5. However, the magnitudes of the declines in total emissions are not consistent across all pollutants, and there are some increases for CO, which reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the proposed standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in VMT. Instances where downstream (tailpipe) emissions are predicted to increase[26] (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline. Tables 4.2.1-1 and 4.2.1-3 show that total emissions of all criteria pollutants in a given year decrease steadily from Alternative 1 through Alternative 5 (except that CO emissions increase slightly from the Preferred Alternative to Alternative 4 in 2018 and 2050).

Under each action alternative compared to the No Action Alternative, the greatest relative reductions in emissions among the criteria pollutants occur for NO_x and VOCs, for which emissions decrease by as much as 37 percent by 2050 compared to the No Action Alternative. Percentage reductions in emissions of CO, PM2.5, and SO_2 compared to the No Action Alternative are less.

[26] Criteria pollutant emissions do not increase above the vehicle emissions standards but rather increase within the allowable "headroom" of the standard.

Table 4.2.1-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	0	-104	-136	-121	-138
2025	0	-20,131	-29,526	-30,213	-39,981
2035	0	-63,855	-82,988	-83,194	-101,059
2050	0	-92,107	-117,312	-117,119	-140,093
Nitrogen oxides (NO_X)					
2018	0	-577	-708	-733	-901
2025	0	-70,038	-101,875	-105,698	-138,254
2035	0	-218,649	-291,161	-293,816	-354,186
2050	0	-313,897	-413,372	-413,840	-491,923
Particulate matter (PM2.5)					
2018	0	-33	-42	-44	-54
2025	0	-144	-367	-634	-951
2035	0	-125	-1,504	-1,674	-2,433
2050	0	-48	-2,161	-2,200	-3,216
Sulfur dioxide (SO_2)					
2018	0	-174	-227	-245	-293
2025	0	-3,841	-6,155	-7,652	-10,461
2035	0	-10,357	-19,705	-20,658	-26,713
2050	0	-14,139	-27,850	-28,133	-36,110
Volatile organic compounds (VOC)					
2018	0	-180	-231	-247	-295
2025	0	-10,646	-16,124	-17,891	-24,108
2035	0	-32,622	-48,671	-49,743	-62,012
2050	0	-46,443	-69,020	-69,245	-85,166

Notes:

[a] Emissions changes are rounded to the nearest whole number.

[b] Negative emissions changes indicate reductions; positive emissions changes are increases.

[c] Emissions changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

The differences in national emissions of criteria air pollutants among the action alternatives compared to the No Action Alternative range from small (less than 1 percent) to large (up to 37 percent) due to the interactions of the multiple factors described above. The small differences are not expected to lead to measurable changes in concentrations of criteria pollutants in the ambient air. The large differences in emissions could lead to changes in ambient pollutant concentrations.

Figure 4.2.1-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts

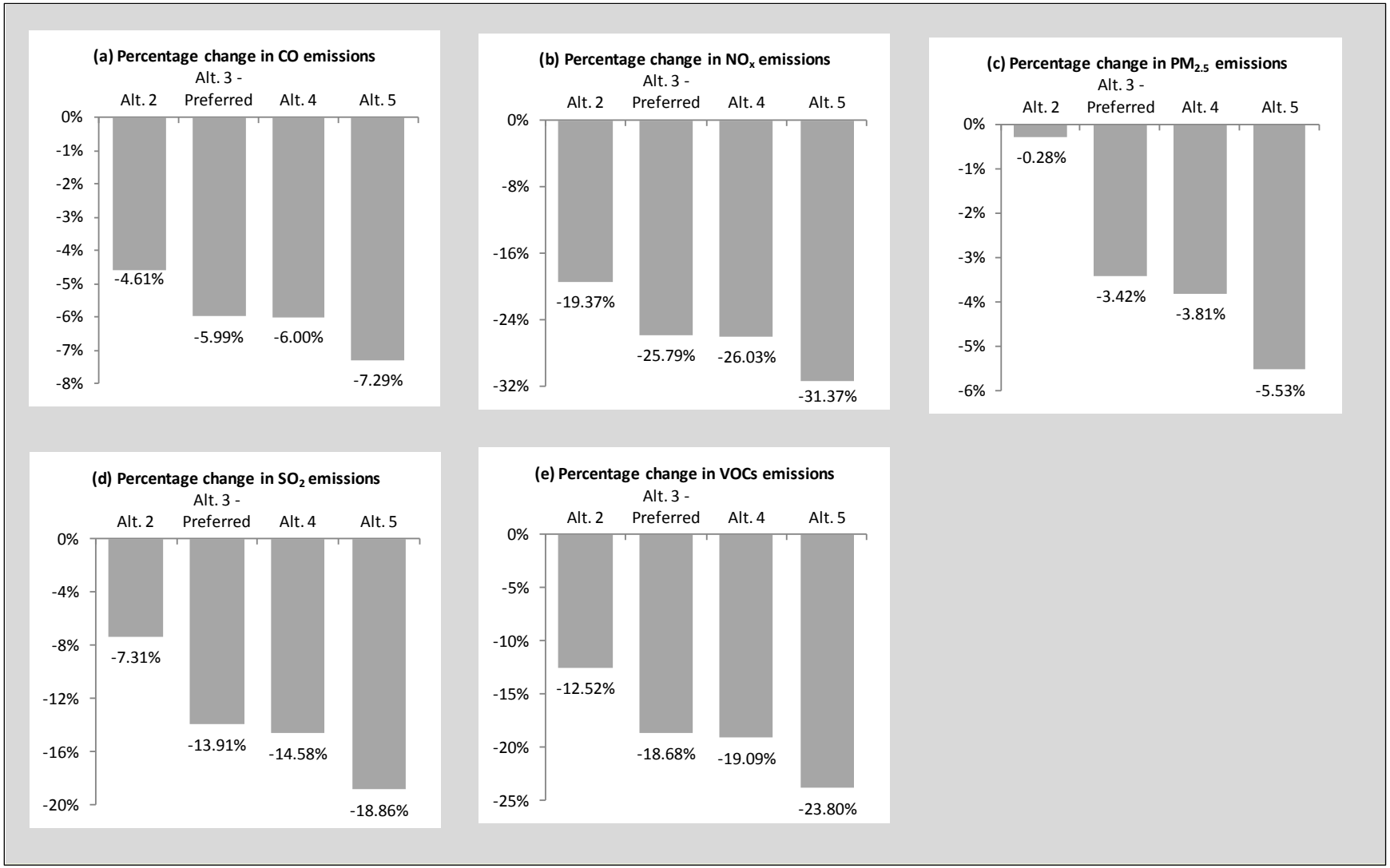


Table 4.2.1-4 summarizes the criteria air pollutant analysis results by nonattainment area. Tables in Appendix A list the emissions changes for each nonattainment area. For CO, Appendix A indicates that most nonattainment areas would experience increases in emissions in 2018 under all the action alternatives, but most would experience decreases in emissions in 2025, 2035, and 2050 under all the action alternatives. For NO_x, most nonattainment areas would experience decreases in emissions across all alternatives and years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under all the action alternatives, but most would experience increases in emissions in 2025, 2035, and 2050 under all the action alternatives. For SO_2 and VOCs, most nonattainment areas would experience decreases in emissions across all alternatives and years.

Table 4.2.1-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Criteria Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area (NAAQS Standard[s])
Carbon monoxide (CO)	Maximum Increase	< 1	2018	Alt. 5	Atlanta, GA (Ozone [1997 8-hr]; PM2.5 [1997 annual])
	Maximum Decrease	-5,800	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA (CO [1971 8-hr]; NO_2 [1971 annual])
Nitrogen oxides (NO_X)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-19,219	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
Particulate matter (PM2.5)	Maximum Increase	89	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-311	2050	Alt. 5	Baton Rouge, LA (Ozone [1997 8-hr]; Ozone [2008 8-hr])
Sulfur dioxide (SO_2)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-2,614	2050	Alt. 5	Beaumont/Port Arthur, TX (Ozone [1997 8-hr])
Volatile organic compounds (VOC)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-3,071	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])

4.2.1.1.2 Toxic Air Pollutants Overview

Table 4.2.1-5 summarizes the total upstream and downstream[27] emissions of toxic air pollutants from HD vehicles by alternative for each of the toxic air pollutants and analysis years. The trends for toxic air pollutant emissions across the alternatives generally show decreases for the same reasons as for criteria pollutants (*see* Section 4.2.1.1.1). These tables show that emissions of acetaldehyde, acrolein, benzene,

[27] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

1,3-butadiene, DPM, and formaldehyde generally remain the same or decrease from Alternative 1 to Alternative 5. These trends are accounted for by the extent of technologies assumed to be deployed under the different alternatives to meet the different levels of fuel efficiency requirements.

Table 4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	8,308	8,308	8,308	8,308	8,308
2025	6,569	6,099	5,897	5,896	5,693
2035	6,164	4,630	4,270	4,270	3,910
2050	7,402	5,180	4,718	4,719	4,257
Acrolein					
2018	1,335	1,335	1,335	1,335	1,335
2025	982	914	884	884	855
2035	868	647	595	595	544
2050	1,041	720	654	654	587
Benzene					
2018	3,364	3,363	3,363	3,363	3,363
2025	2,563	2,465	2,419	2,412	2,363
2035	2,283	1,967	1,863	1,858	1,768
2050	2,649	2,195	2,055	2,055	1,937
1,3-Butadiene					
2018	604	604	604	604	604
2025	322	315	313	313	309
2035	180	160	155	155	150
2050	197	170	163	163	157
Diesel particulate matter (DPM)					
2018	136,808	136,766	136,754	136,752	136,740
2025	102,611	102,524	102,202	101,872	101,426
2035	91,096	91,009	89,208	89,001	87,960
2050	108,745	108,726	105,972	105,931	104,542
Formaldehyde					
2018	21,015	21,015	21,015	21,015	21,015
2025	18,472	16,989	16,353	16,349	15,710
2035	18,742	13,911	12,772	12,771	11,636
2050	22,688	15,690	14,226	14,227	12,770

Figure 4.2.1-4 shows toxic air pollutant emissions for each alternative in 2035, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the Proposed Action.

Figure 4.2.1-4. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Direct and Indirect Impacts

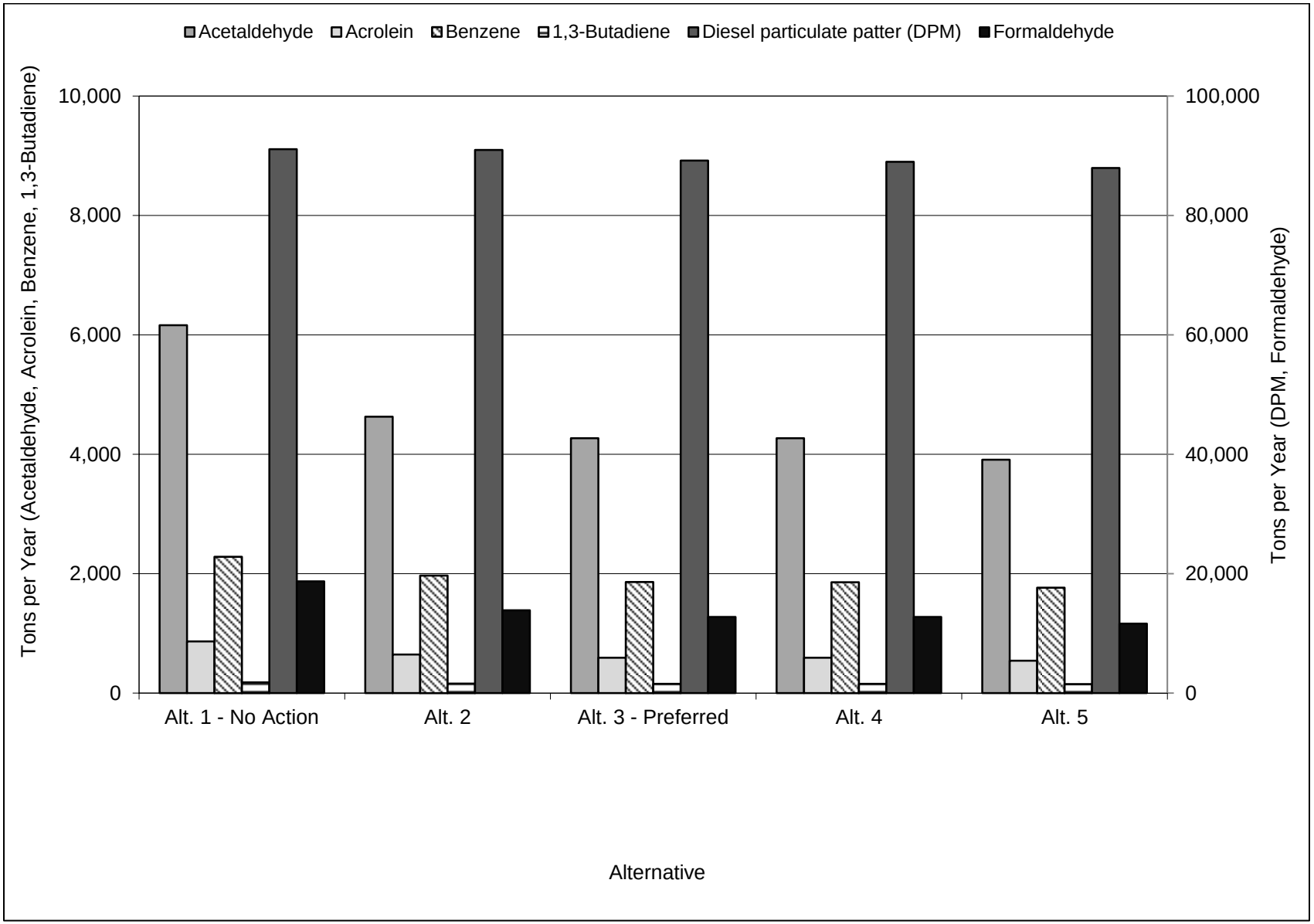


Figure 4.2.1-5 summarizes the changes over time in total national emissions of toxic air pollutants from HD vehicles under the Preferred Alternative. This figure indicates a consistent trend among the toxic air pollutants. Emissions decline from 2018 to 2035 due to increasingly stringent EPA regulation of emissions from vehicles and from reductions in upstream emissions from fuel production, but increase from 2035 to 2050 due to continuing growth in VMT.

As with criteria pollutant emissions (*see* Section 4.2.1.1.1), total toxic pollutant emissions are made up of six components, consisting of two sources of emissions (downstream and upstream) for each of the three HD vehicle classes covered by the proposed rule. (Emissions associated with the tractor-trailer classes include effects of proposed trailer standards.) To show the relationship among these six components for toxic air pollutants, Table 4.2.1-6 breaks down the total emissions of air toxic pollutants by component for calendar year 2035.

Table 4.2.1-7 lists the net change in nationwide emissions from HD vehicles for each of the toxic air pollutants and analysis years under the action alternatives compared to the No Action Alternative. The table shows that the magnitude of nationwide emissions changes tends to increase from 2018 to 2050. Figure 4.2.1-6 shows these changes in percentages for 2035. For each combination of pollutant and year, the emissions generally remain the same or decrease from Alternative 2 to Alternative 5, reflecting the increasing stringency of the alternatives.

The differences in national emissions of toxic air pollutants among the action alternatives compared to the No Action Alternative range from small (less than 1 percent) to large (up to 44 percent) due to the interactions of the multiple factors described above in Section 4.2.1.1.1. The small differences are not expected to lead to measurable changes in concentrations of toxic air pollutants in the ambient air. For such small changes, the impacts of those action alternatives would be essentially equivalent. The large differences in emissions could lead to changes in ambient pollutant concentrations.

Figure 4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Direct and Indirect Impacts

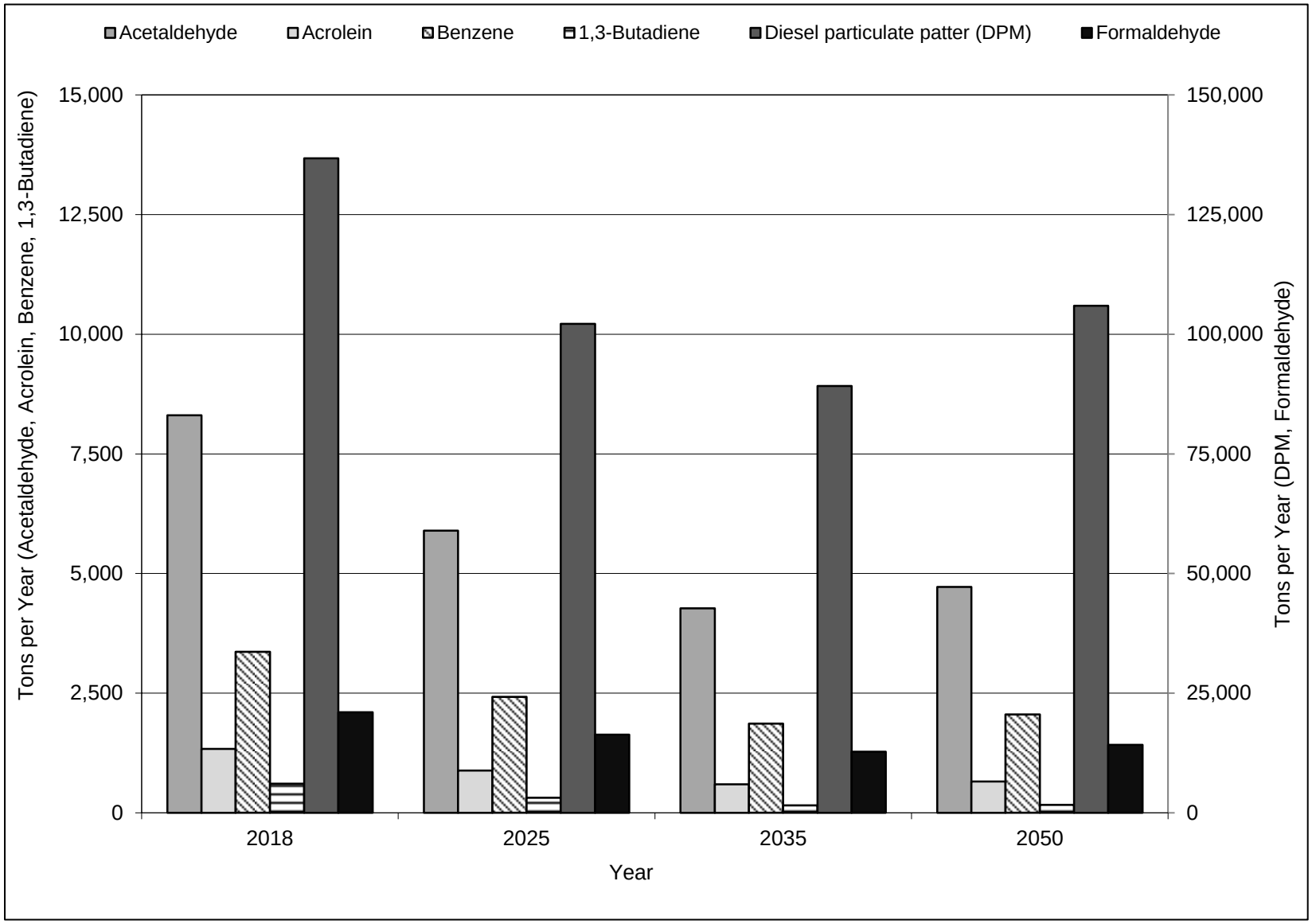


Table 4.2.1-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Direct and Indirect Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
Classes 2b–3 Work Trucks Tailpipe	471	473	474	475	475
Classes 2b–3 Work Trucks Upstream	5	5	5	5	4
Classes 3–8 Vocational Vehicles Tailpipe	580	585	585	585	585
Classes 3–8 Vocational Vehicles Upstream	53	52	49	48	46
Classes 7–8 Combination Unit Tailpipe	5,021	3,484	3,129	3,129	2,773
Classes 7–8 Combination Unit Upstream	34	31	29	28	27
Total	6,164	4,630	4,270	4,270	3,910
Acrolein					
Classes 2b–3 Work Trucks Tailpipe	54	54	54	54	54
Classes 2b–3 Work Trucks Upstream	1	1	1	1	1
Classes 3–8 Vocational Vehicles Tailpipe	77	78	78	78	78
Classes 3–8 Vocational Vehicles Upstream	5	5	4	4	4
Classes 7–8 Combination Unit Tailpipe	727	505	454	454	403
Classes 7–8 Combination Unit Upstream	5	4	4	4	4
Total	868	647	595	595	544
Benzene					
Classes 2b–3 Work Trucks Tailpipe	444	445	448	448	449
Classes 2b–3 Work Trucks Upstream	89	84	79	78	76
Classes 3–8 Vocational Vehicles Tailpipe	334	337	335	334	333
Classes 3–8 Vocational Vehicles Upstream	191	188	175	174	164
Classes 7–8 Combination Unit Tailpipe	937	650	584	584	518
Classes 7–8 Combination Unit Upstream	288	262	242	241	227
Total	2,283	1,967	1,863	1,858	1,768
1,3-Butadiene					
Classes 2b–3 Work Trucks Tailpipe	70	70	70	70	70
Classes 2b–3 Work Trucks Upstream	2	2	2	2	2
Classes 3–8 Vocational Vehicles Tailpipe	25	25	25	25	25
Classes 3–8 Vocational Vehicles Upstream	4	4	4	4	4
Classes 7–8 Combination Unit Tailpipe	62	44	40	40	36
Classes 7–8 Combination Unit Upstream	16	15	14	14	13
Total	180	160	155	155	150

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Diesel particulate matter (DPM)					
Classes 2b–3 Work Trucks Tailpipe	407	409	410	410	411
Classes 2b–3 Work Trucks Upstream	2,836	2,683	2,534	2,497	2,448
Classes 3–8 Vocational Vehicles Tailpipe	13,739	13,957	13,953	13,952	13,948
Classes 3–8 Vocational Vehicles Upstream	5,867	5,703	5,305	5,260	4,965
Classes 7–8 Combination Unit Tailpipe	47,817	49,676	49,842	49,821	50,089
Classes 7–8 Combination Unit Upstream	20,429	18,581	17,165	17,060	16,100
Total	91,096	91,009	89,208	89,001	87,960
Formaldehyde					
Classes 2b–3 Work Trucks Tailpipe	994	1,000	1,002	1,003	1,004
Classes 2b–3 Work Trucks Upstream	41	39	37	36	36
Classes 3–8 Vocational Vehicles Tailpipe	1,630	1,647	1,647	1,647	1,647
Classes 3–8 Vocational Vehicles Upstream	93	90	84	83	79
Classes 7–8 Combination Unit Tailpipe	15,698	10,875	9,762	9,763	8,646
Classes 7–8 Combination Unit Upstream	286	260	240	239	225
Total	18,742	13,911	12,772	12,771	11,636

Table 4.2.1-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	0	0	0	0	0
2025	0	-470	-672	-673	-875
2035	0	-1,534	-1,893	-1,893	-2,253
2050	0	-2,222	-2,683	-2,683	-3,144
Acrolein					
2018	0	0	0	0	0
2025	0	-68	-97	-97	-127
2035	0	-221	-273	-273	-324
2050	0	-321	-387	-387	-454
Benzene					
2018	0	-1	-1	-1	-1
2025	0	-99	-144	-151	-201
2035	0	-316	-420	-425	-515
2050	0	-454	-594	-594	-712
1,3-Butadiene					
2018	0	0	0	0	0
2025	0	-7	-9	-9	-13
2035	0	-19	-25	-25	-30
2050	0	-28	-35	-34	-41
Diesel particulate matter (DPM)					
2018	0	-42	-54	-56	-67
2025	0	-87	-409	-739	-1,185
2035	0	-86	-1,887	-2,095	-3,135
2050	0	-19	-2,773	-2,814	-4,203
Formaldehyde					
2018	0	1	0	0	0
2025	0	-1,483	-2,119	-2,123	-2,763
2035	0	-4,831	-5,970	-5,970	-7,105
2050	0	-6,998	-8,462	-8,461	-9,918

Notes:

[a] Emissions changes are rounded to the nearest whole number.

[b] Negative emissions changes indicate reductions; positive emissions changes are increases.

[c] Emissions changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

Figure 4.2.1-6 (a)–(f). Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts

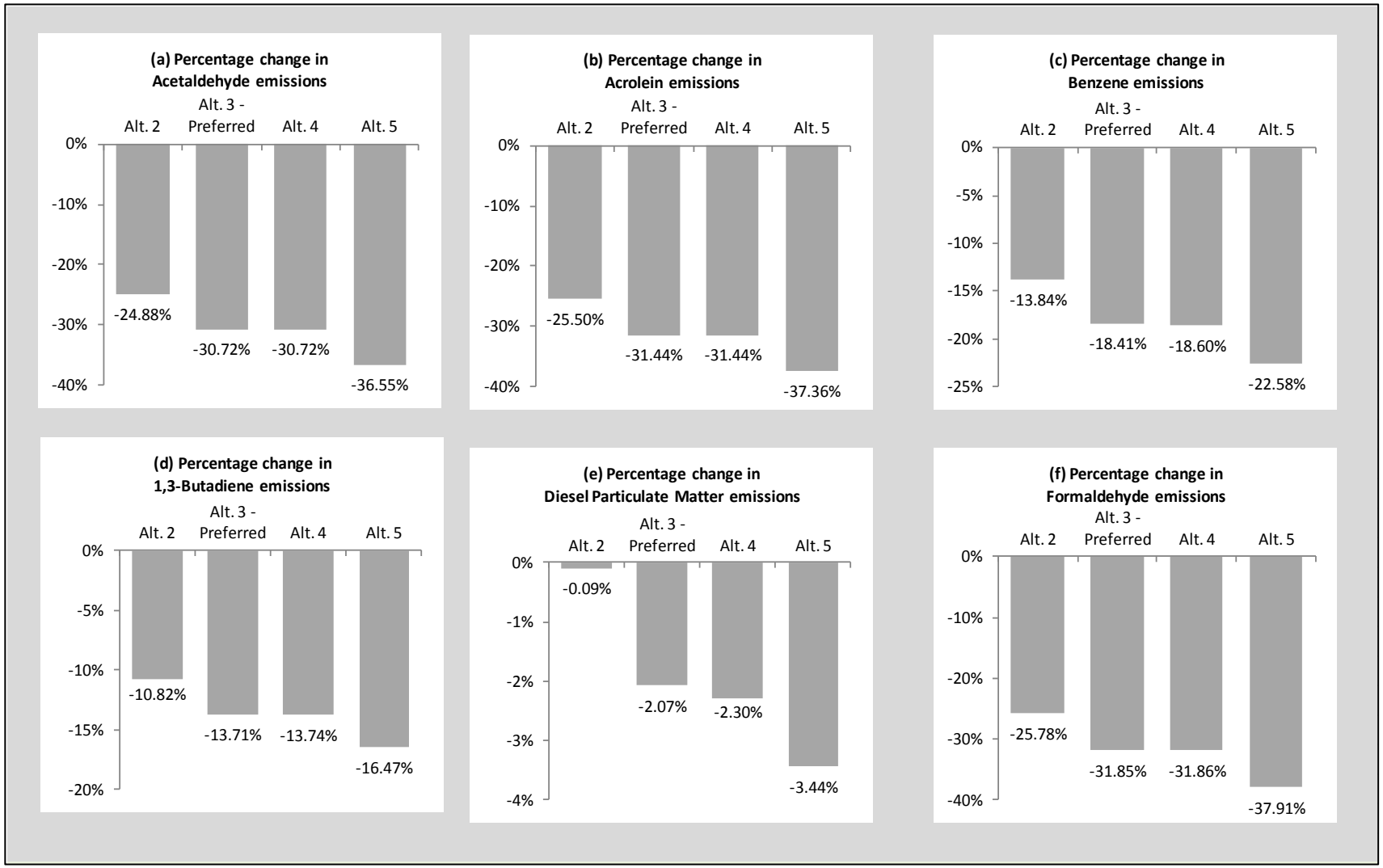


Table 4.2.1-8 summarizes the air toxics analysis results by nonattainment area.[28] Tables in Appendix A list the estimated emissions changes for each nonattainment area. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, Appendix A indicates that most nonattainment areas experience increases in emissions in 2018 under all the action alternatives, but decreases in 2025, 2035, and 2050 under all the action alternatives. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under all the action alternatives. For DPM, most nonattainment areas experience decreases in emissions in 2018 under all the action alternatives, but increases in 2025, 2035, and 2050 under all the action alternatives.

Table 4.2.1-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Criteria Pollutant	Maximum Increase/ Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum Increase	<1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
	Maximum Decrease	-135	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
Acrolein	Maximum Increase	<1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
	Maximum Decrease	-20	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
Benzene	Maximum Increase	<1	2018	Alt. 5	Riverside County; Coachella Valley planning area, CA [PM 10 (1987 24-hour)]
	Maximum Decrease	-26	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
1,3-Butadiene	Maximum Increase	<1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
	Maximum Decrease	-2	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (1997 8-hr)]
Diesel particulate matter (DPM)	Maximum Increase	111	2050	Alt. 2	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
	Maximum Decrease	-399	2050	Alt. 5	Baton Rouge, LA [Ozone (1997 8-hr); Ozone (2008 8-hr)]
Formaldehyde	Maximum Increase	<1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]
	Maximum Decrease	-424	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (1997 8-hr)]

[28] EPA has not established NAAQS for airborne toxics. Therefore, none of these areas is classified as a nonattainment area as a result of airborne toxics emissions. Toxic air pollutant emissions data for nonattainment areas are provided for information only.

4.2.1.1.3 Health Effects and Monetized Health Benefits Overview

Adverse health effects would decrease nationwide under each of the action alternatives compared to the No Action Alternative (*see* Table 4.2.1-9). As described in Section 4.1.2.7.2, the changes in PM mortality shown in these tables are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). While the number of PM mortalities varies between the two methods, the percent change in mortality across alternatives and years is equal. The health benefits across all outcomes remain the same or increase from Alternative 2 to Alternative 5 and from near-future (2018) to later years (2050). For each combination of pollutant and year, the health benefits increase from Alternative 2 to Alternative 5, reflecting the increasing stringency of the alternatives.

Table 4.2.1-9. Nationwide Changes in Health Outcomes (cases per year) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Outcome and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Premature mortality - Krewski et al. (2009)					
2018	0	-3	-4	-4	-5
2025	0	-99	-156	-183	-248
2035	0	-308	-525	-544	-692
2050	0	-429	-746	-751	-944
Premature mortality – Lepeule et al. (2012)					
2018	0	-7	-8	-9	-11
2025	0	-225	-353	-415	-563
2035	0	-707	-1,197	-1,239	-1,573
2050	0	-987	-1,700	-1,710	-2,148
Acute bronchitis					
2018	0	-5	-6	-6	-8
2025	0	-156	-246	-289	-393
2035	0	-462	-787	-815	-1,035
2050	0	-645	-1,117	-1,124	-1,413
Work-loss days					
2018	0	-412	-522	-556	-672
2025	0	-13,162	-20,692	-24,313	-32,994
2035	0	-37,464	-64,389	-66,761	-84,927
2050	0	-52,197	-91,429	-92,029	-115,887
Emergency room visits – respiratory					
2018	0	-2	-2	-2	-3
2025	0	-51	-81	-94	-128
2035	0	-155	-262	-271	-343
2050	0	-217	-372	-374	-469

[a] Incidence estimates are rounded to the nearest whole number.

[b] Negative changes indicate fewer health impacts; positive changes indicate additional health impacts.

[c] Changes for the No Action Alternative are shown as zero because it is the baseline to which the other alternatives are compared.

The monetized health benefits follow similar trends to the changes in health outcomes. Table 4.2.1-10 lists the corresponding monetized health benefits under the action alternatives compared to the No Action Alternative. Monetized health benefits are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). Under each action alternative, the monetized health benefits increase from 2018 to 2050. In each analysis year, the monetized health benefits of each action alternative increase from Alternative 2 (least stringent) to Alternative 5 (most stringent).

Table 4.2.1-10. Nationwide Monetized Health Benefits (U.S. million dollars per year, 2012$) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Rate and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
3-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$30	$39	$41	$50
2025	$0	$1,037	$1,627	$1,907	$2,587
2035	$0	$3,439	$5,872	$6,085	$7,731
2050	$0	$4,796	$8,338	$8,391	$10,554
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$69	$88	$93	$113
2025	$0	$2,342	$3,677	$4,310	$5,845
2035	$0	$7,826	$13,281	$13,754	$17,458
2050	$0	$10,921	$18,857	$18,976	$23,838
7-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$28	$35	$37	$45
2025	$0	$932	$1,463	$1,714	$2,324
2035	$0	$3,088	$5,266	$5,456	$6,931
2050	$0	$4,306	$7,477	$7,525	$9,462
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$61	$78	$83	$100
2025	$0	$2,097	$3,292	$3,861	$5,238
2035	$0	$7,036	$11,966	$12,395	$15,738
2050	$0	$9,818	$16,991	$17,099	$21,489

Notes:

[a] Monetized health benefit estimates are rounded to the nearest whole number

[b] Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts.

[c] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

Sections 4.2.1.2 through 4.2.1.5 describe the results of the analysis of emissions for Alternatives 1 through 5 in more detail. The magnitude of emissions change from one alternative to the next generally

increases, with a few exceptions that are discussed in these sections, between Alternative 2 and Alternative 5 consistent with increases in overall fuel efficiency.

4.2.1.2 Alternative 1 - No Action

4.2.1.2.1 Criteria Pollutants

The No Action Alternative assumes market-based gains in new HD vehicle fuel efficiency after 2018. Current trends in the levels of criteria pollutant emissions from vehicles would continue under the No Action Alternative, with emissions of CO, NO_X, PM2.5, and VOCs continuing to decline due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2035, but increasing from 2035 to 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.1-1 and Figure 4.2.1-1). Total emissions of SO_2 under the No Action Alternative are predicted to increase from 2018 to 2050 because declines due to market-based gains in new vehicle HD vehicle fuel efficiency are more than offset by growth in VMT beginning before 2018. The No Action Alternative would not change these trends and, therefore, would not result in any change in criteria pollutant emissions nationally or in nonattainment areas beyond changes projected to result from future trends in emissions and VMT (*see* Table 4.2.1-1).

Figure 4.2.1-1 shows that emissions of CO, NO_X, PM2.5, SO_2, and VOCs under the No Action Alternative would be greater than emissions under all of the action alternatives. Changes in emissions of all criteria pollutants would generally be greatest in 2050 under Alternative 5, in which emissions would range up to 37 percent less than under the No Action Alternative.

4.2.1.2.2 Toxic Air Pollutants

EPA regulates toxic air pollutants from motor vehicles through vehicle emissions standards and fuel quality standards, as discussed in Section 4.1.1. As with the criteria pollutants, current trends in the levels of toxic air pollutant emissions from vehicles would continue under the No Action Alternative. Emissions would continue to decline in early years due to the EPA emissions standards (*see* Section 4.1.1) despite a growth in total VMT, reaching a minimum in 2035 (2025 for formaldehyde), but increasing in 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.1-5 and Figure 4.2.1-4). The No Action Alternative would not change the current fuel efficiency standards for HD vehicles and, therefore, would not result in any change in toxic air pollutant emissions throughout the United States beyond projected trends shown for the No Action Alternative in Table 4.2.1-4.

Figure 4.2.1-4 shows that emissions of acrolein, acetaldehyde, benzene, 1,3-butadiene, DPM, and formaldehyde under the No Action Alternative are the same as or greater than emissions under all of the action alternatives. Changes in emissions of all toxic air pollutants are greatest in 2050 under Alternative 5, in which emissions range up to 44 percent less than under the No Action Alternative.

4.2.1.2.3 Health Outcomes and Monetized Benefits

Under the No Action Alternative, current trends in the levels of criteria pollutant and toxic air pollutant emissions from vehicles would continue, with emissions of most criteria pollutants decreasing initially and then increasing to 2050 due to growth in total VMT, which more than offsets reductions due to the EPA vehicle emissions standards (*see* Section 4.1.1). The human health-related trends would continue

(*see* Tables 4.2.1-9 and 4.2.1-10). The No Action Alternative would not result in any additional increase or decrease in human health effects throughout the United States.

4.2.1.3 Alternative 2

4.2.1.3.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 2 compared to the No Action Alternative and the action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2035. Under Alternative 2, nationwide emissions of all criteria pollutants would decrease compared to the No Action Alternative. Alternative 2 is the least stringent of all the action alternatives, and the emissions reductions under Alternative 2 would be less than those under the Preferred Alternative, Alternative 4, and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 2 compared to the No Action Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 2, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in emissions in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under Alternative 2, but increases in 2025, 2035, and 2050. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.3.2 Toxic Air Pollutants

Table 4.2.1-5 shows the changes in nationwide emissions of toxic air pollutants under Alternative 2 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-6 shows these changes in percentages for 2035. Compared to the No Action Alternative, Alternative 2 would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Alternative 2 would result in the same or higher emissions than would the other action alternatives.

At the national level, emissions of all toxic air pollutants could decrease under Alternative 2 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas would experience increases in emissions in 2018 under Alternative 2, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas would experience decreases in emissions in all analysis years under Alternative 2. For DPM, most nonattainment areas would experience decreases in emissions in 2018 under Alternative 2, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.1.3.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 2 compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under Alternative 2 would range from a

minimum benefit of $28 million per year to a maximum benefit of $10.9 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under Alternative 2 are less than those under the other action alternatives.

4.2.1.4 Alternative 3 - Preferred Alternative

4.2.1.4.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under the Preferred Alternative compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2035. Figure 4.2.1-2 shows criteria pollutant emissions under the Preferred Alternative by year. Under this alternative, emissions of all criteria pollutants would decrease compared to the No Action Alternative. This alternative would reduce emissions more than Alternative 2. Emissions under the Preferred Alternative would be less than under Alternative 2, but greater than under Alternative 4 (except for CO in 2018 and 2050) and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under the Preferred Alternative, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under the Preferred Alternative, but increases in 2025, 2035, and 2050. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.4.2 Toxic Air Pollutants

Table 4.2.1-7 shows the changes in nationwide emissions of toxic air pollutants under the Preferred Alternative compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-5 shows toxic pollutant emissions under the Preferred Alternative by year. Figure 4.2.1-6 shows these changes in percentage terms for 2035. Compared to the No Action Alternative, the Preferred Alternative would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. The Preferred Alternative would result in lower emissions than would Alternative 2, but the same or higher emissions than would Alternative 4 and Alternative 5 (except that acetaldehyde and formaldehyde emissions are slightly lower than under Alternative 4 in 2050).

At the national level, emissions of all toxic air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under the Preferred Alternative, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under the Preferred Alternative. For DPM, most nonattainment areas experience decreases in emissions in 2018 under the Preferred Alternative, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.1.4.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under the Preferred Alternative compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under the Preferred Alternative would range from a minimum benefit of $35 million per year to a maximum benefit of $18.9 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under the Preferred Alternative are greater than those under Alternative 2 but less than those under Alternative 4 and Alternative 5.

4.2.1.5 Alternative 4

4.2.1.5.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2035. Under this alternative, emissions of all criteria pollutants would decrease compared to the No Action Alternative. This alternative would reduce emissions more than Alternative 2 and the Preferred Alternative (except that CO emissions under Alternative 4 would be slightly higher than under the Preferred Alternative in 2018 and 2050). With this exception, emissions under Alternative 4 would be less than under Alternative 2 and the Preferred Alternative, but greater than under Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 4, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under the Preferred Alternative, but increases in emissions in 2025, 2035, and 2050. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.5.2 Toxic Air Pollutants

Table 4.2.1-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-5 shows toxic pollutant emissions under the Preferred Alternative by year. Figure 4.2.1-6 shows these changes in percentage terms for 2035. Compared to the No Action Alternative, Alternative 4 would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Alternative 4 would result in the same or lower emissions than would Alternative 2 and the Preferred Alternative (except that acetaldehyde and formaldehyde emissions are slightly higher than under the Preferred Alternative in 2050), but the same or higher emissions than would Alternative 5.

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas.

For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 4, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 4. For DPM, most nonattainment areas experience decreases in emissions in 2018 under Alternative 4, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.1.5.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 4 compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under Alternative 4 would range from a minimum benefit of $37 million per year to a maximum benefit of $19.0 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 4 are greater than those under Alternative 2 and Preferred Alternative but less than those under Alternative 5.

4.2.1.6 Alternative 5

4.2.1.6.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2035. Under this alternative, emissions of all criteria pollutants would decrease compared to the No Action Alternative. This alternative would reduce emissions more than Alternative 2, the Preferred Alternative, and Alternative 4. Emissions under Alternative 5 would be less than under Alternative 2, the Preferred Alternative, and Alternative 4.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 5, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under Alternative 5, but increases in emissions in 2025, 2035, and 2050. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.6.2 Toxic Air Pollutants

Table 4.2.1-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-5 shows toxic pollutant emissions under Alternative 5 by year. Figure 4.2.1-6 shows these changes in percentage terms for 2035. Compared to the No Action Alternative, Alternative 5 would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Alternative 5 would result in lower emissions than would Alternative 2, the Preferred Alternative, and Alternative 4.

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the

decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 5, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 5. For DPM, most nonattainment areas experience decreases in emissions in 2018 under Alternative 5, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.1.6.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 5 compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under Alternative 5 would range from a minimum benefit of $45 million per year to a maximum benefit of $23.8 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 5 are greater than those under Alternative 2, the Preferred Alternative, and Alternative 4.

4.2.2 Cumulative Impacts

4.2.2.1 Results of the Analysis

This section examines cumulative air quality impacts of the action alternatives, using the assumptions discussed in Section 2.3.[29] The tables and figures in Section 4.2.2 and its subsections present the projected cumulative impacts of the action alternatives on air quality. Following the comparative overview in this section, Sections 4.2.2.2 through 4.2.2.5 describe the results of the analysis of cumulative emissions impacts under Alternatives 1 through 5 in more detail.

4.2.2.1.1 Criteria Pollutants Overview

Table 4.2.2-1 summarizes the total upstream and downstream[30] national emissions from HD vehicles by alternative for each of the criteria pollutants and analysis years. Figure 4.2.2-1 illustrates this information for 2035, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the Proposed Action. Figure 4.2.2-2 summarizes the changes over time in total national emissions of criteria pollutants from HD vehicles under the Preferred Alternative. Figures 4.2.2-1 and 4.2.2-2 show a consistent trend among the criteria pollutants. Emissions of CO, NO_X, PM2.5, and VOCs would decrease due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2035, but increase from 2035 to 2050 because continued growth in total VMT during that period would overwhelm the initial decreases (*see* Table 4.2.2-1 and Figure 4.2.2-1). (Note that continued growth in VMT is projected to occur under all alternatives). Emissions of SO_2 under all alternatives are predicted to increase from 2018 to 2050 because declines due to gains in new HD vehicle fuel efficiency are more than offset by continuing growth in VMT. Alternative 5 is sufficiently stringent that fuel savings would offset VMT growth even in

[29] As explained in Chapter 2, the cumulative impacts analysis compares the same action alternatives with a No Action Alternative that generally assumes no increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond (i.e., no increase beyond the 2014-2018 Phase 1 standards). In other words, this baseline generally does not take into account market-based incentives for improving fuel efficiency. By comparing the action alternatives to this baseline, the cumulative impacts analysis reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 and the direct and indirect impacts of Phase 2 HD standards associated with each action alternative.

[30] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

the early years of Phase 2 implementation, and SO_2 emissions would decrease continuously from 2018 to 2035 before increasing by 2050 due to continued VMT growth.

Table 4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	2,022,131	2,022,050	2,022,019	2,022,034	2,022,016
2025	1,614,037	1,593,854	1,584,461	1,583,774	1,574,005
2035	1,387,411	1,322,541	1,303,407	1,303,202	1,285,336
2050	1,558,831	1,465,076	1,439,871	1,440,064	1,417,090
Nitrogen oxides (NO_X)					
2018	2,185,365	2,184,866	2,184,735	2,184,710	2,184,542
2025	1,430,837	1,359,701	1,327,865	1,324,042	1,291,485
2035	1,137,634	910,303	837,790	835,135	774,765
2050	1,340,388	1,012,596	913,122	912,654	834,570
Particulate matter (PM2.5)					
2018	97,458	97,430	97,422	97,419	97,410
2025	60,153	59,964	59,741	59,475	59,158
2035	44,363	43,860	42,481	42,311	41,552
2050	51,912	51,269	49,155	49,117	48,101
Sulfur dioxide (SO_2)					
2018	121,065	120,924	120,871	120,853	120,806
2025	129,981	125,916	123,602	122,105	119,296
2035	143,430	131,283	121,936	120,982	114,928
2050	170,476	153,560	139,849	139,566	131,589
Volatile organic compounds (VOC)					
2018	342,765	342,620	342,568	342,552	342,504
2025	278,427	267,595	262,117	260,349	254,133
2035	262,242	227,885	211,836	210,765	198,496
2050	310,062	260,890	238,313	238,088	222,168

The timing of the increases between 2018 and 2050 varies by alternative. EPA regulates vehicle SO_2 emissions by limiting the concentration of sulfur in fuel and has not established tailpipe emissions standards for SO_2. As a result, SO_2 emissions vary only with total fuel consumption. Under the No Action Alternative, which assumes neither NHTSA nor EPA promulgate Phase 2 standards (i.e., the No Action Alternative), total fuel consumption would rise as VMT grows, and SO_2 emissions would increase continuously from 2018 to 2050. Alternative 2 is not sufficiently stringent for fuel savings to offset VMT growth, so SO_2 emissions would increase continuously from 2018 to 2050 under Alternative 2 as well. Under Alternatives 3 and 4, SO_2 emissions would increase from 2018 to 2025 but would decrease by 2035 as the proportion of all vehicles that meets the Phase 2 standards increases, before emissions increase again by 2050 due to continued VMT growth.

Figure 4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Cumulative Impacts

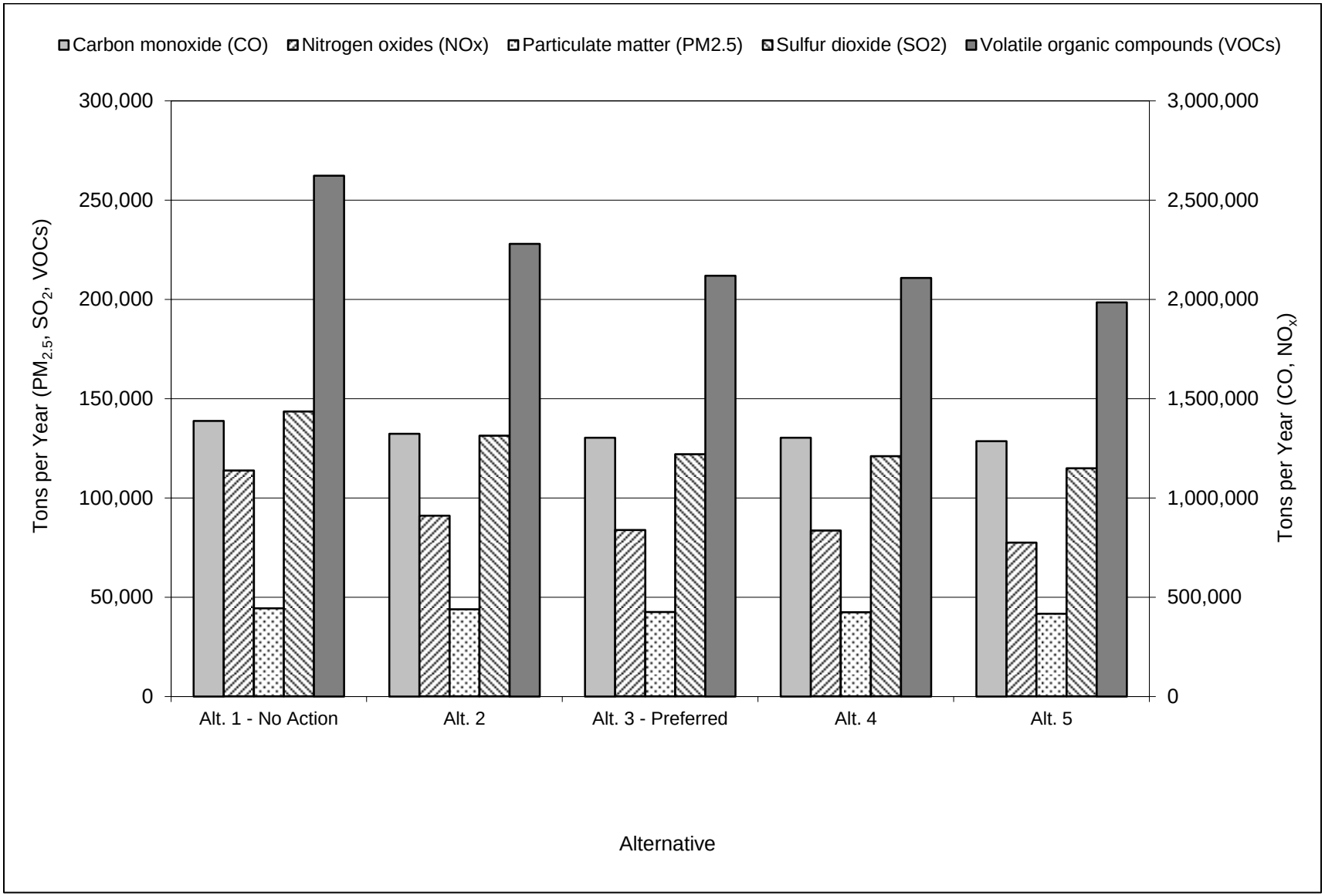
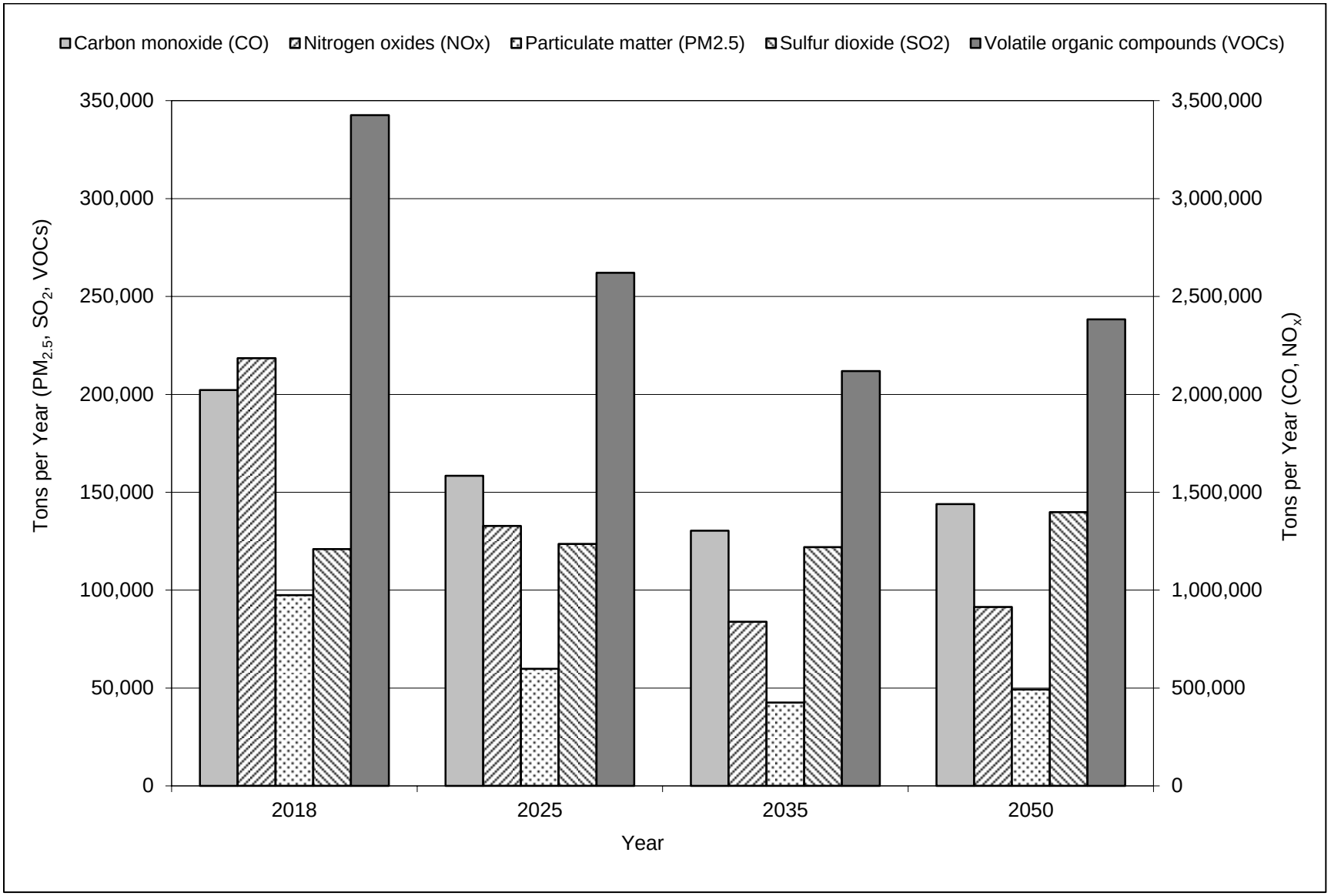


Figure 4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Cumulative Impacts



Total emissions are made up of six components, consisting of two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three vehicle classes covered by the proposed rule: Classes 2b–3 HD pickups and vans, Classes 3–8 vocational vehicles, and Classes 7–8 tractor-trailers. (Emissions associated with the tractor-trailer classes include effects of proposed trailer standards.) To show the relationship among these six components for criteria pollutants, Table 4.2.2-2 breaks down the total emissions of criteria pollutants by component for calendar year 2035.

Table 4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Cumulative Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
Classes 2b–3 Work Trucks Tailpipe	327,370	329,060	330,615	331,042	331,588
Classes 2b–3 Work Trucks Upstream	10,399	9,708	9,177	9,046	8,869
Classes 3–8 Vocational Vehicles Tailpipe	657,139	659,084	658,786	658,753	658,429
Classes 3–8 Vocational Vehicles Upstream	16,147	15,681	14,585	14,461	13,649
Classes 7–8 Combination Unit Tailpipe	317,175	256,029	241,305	241,258	226,898
Classes 7–8 Combination Unit Upstream	59,180	52,977	48,939	48,641	45,903
Total	1,387,411	1,322,541	1,303,407	1,303,202	1,285,336
Nitrogen oxides (NO_X)					
Classes 2b–3 Work Trucks Tailpipe	46,747	47,025	47,162	47,214	47,258
Classes 2b–3 Work Trucks Upstream	34,285	32,005	30,261	29,834	29,255
Classes 3–8 Vocational Vehicles Tailpipe	115,395	116,728	116,422	116,390	116,077
Classes 3–8 Vocational Vehicles Upstream	39,524	38,385	35,703	35,399	33,411
Classes 7–8 Combination Unit Tailpipe	757,100	546,728	488,679	487,463	436,619
Classes 7–8 Combination Unit Upstream	144,583	129,430	119,563	118,836	112,145
Total	1,137,634	910,303	837,790	835,135	774,765
Particulate matter (PM2.5)					
Classes 2b–3 Work Trucks Tailpipe	2,002	2,016	2,024	2,027	2,029
Classes 2b–3 Work Trucks Upstream	3,092	2,886	2,732	2,694	2,643
Classes 3–8 Vocational Vehicles Tailpipe	4,240	4,299	4,294	4,293	4,289
Classes 3–8 Vocational Vehicles	4,541	4,416	4,107	4,072	3,845

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Upstream					
Classes 7–8 Combination Unit Tailpipe	14,783	16,185	16,337	16,318	16,565
Classes 7–8 Combination Unit Upstream	15,705	14,059	12,987	12,908	12,181
Total	44,363	43,860	42,481	42,311	41,552
Sulfur dioxide (SO2)					
Classes 2b–3 Work Trucks Tailpipe	552	556	558	559	560
Classes 2b–3 Work Trucks Upstream	22,433	20,942	19,800	19,520	19,141
Classes 3–8 Vocational Vehicles Tailpipe	1,154	1,123	1,044	1,036	978
Classes 3–8 Vocational Vehicles Upstream	24,644	23,930	22,258	22,068	20,828
Classes 7–8 Combination Unit Tailpipe	3,935	3,527	3,261	3,241	3,060
Classes 7–8 Combination Unit Upstream	90,712	81,205	75,014	74,558	70,360
Total	143,430	131,283	121,936	120,982	114,928
Volatile organic compounds (VOC)					
Classes 2b–3 Work Trucks Tailpipe	13,637	13,716	13,771	13,789	13,808
Classes 2b–3 Work Trucks Upstream	18,821	17,587	16,408	16,165	15,766
Classes 3–8 Vocational Vehicles Tailpipe	29,984	29,741	28,563	28,424	27,562
Classes 3–8 Vocational Vehicles Upstream	27,327	26,921	25,044	24,833	23,517
Classes 7–8 Combination Unit Tailpipe	133,655	105,171	95,949	95,648	87,734
Classes 7–8 Combination Unit Upstream	38,818	34,750	32,101	31,905	30,109
Total	262,242	227,885	211,836	210,765	198,496

Table 4.2.2-3 lists the net changes in nationwide criteria pollutant emissions from HD vehicles for each action alternative for each criteria pollutant and analysis year compared to the No Action Alternative in the same year. Figure 4.2.2-3 shows these changes in percentages for 2035. As a general trend, total emissions of each pollutant in a given year decrease from Alternative 2 through Alternative 5, as each successive alternative becomes more stringent. In Table 4.2.2-3, this trend shows as a growing difference between the No Action Alternative and each action alternative from Alternative 2 through Alternative 5. However, the magnitudes of the declines in total emissions are not consistent across all pollutants, and there are some emissions increases for CO, which reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the proposed standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in VMT. Instances where downstream (tailpipe) emissions are predicted to increase[31] (on a per-VMT basis) in the action alternatives would be attributable to shifts in modeled technology adoption from the baseline.

Tables 4.2.1-1 and 4.2.1-3 show that total emissions of all criteria pollutants in a given year would decrease from Alternative 1 through Alternative 5 (except that CO emissions would increase slightly from Alternative 3 to Alternative 4 in 2018 and 2050). Under each action alternative compared to the No Action Alternative, the greatest relative reductions in emissions among the criteria pollutants would occur for NO_x and VOCs, for which emissions would decrease by as much as 38 percent by 2050 compared to the No Action Alternative. Percentage reductions in emissions of CO, PM2.5, and SO_2 compared to the No Action Alternative would be less.

[31] Criteria pollutant emissions do not increase above the vehicle emissions standards but rather increase within the allowable "headroom" of the standard.

Table 4.2.2-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	0	-81	-112	-97	-115
2025	0	-20,182	-29,576	-30,263	-40,032
2035	0	-64,870	-84,004	-84,209	-102,075
2050	0	-93,755	-118,960	-118,767	-141,741
Nitrogen oxides (NOx)					
2018	0	-498	-630	-655	-822
2025	0	-71,136	-102,972	-106,795	-139,352
2035	0	-227,332	-299,845	-302,499	-362,870
2050	0	-327,792	-427,267	-427,735	-505,818
Particulate matter (PM2.5)					
2018	0	-28	-36	-39	-48
2025	0	-189	-412	-678	-995
2035	0	-502	-1,882	-2,051	-2,811
2050	0	-644	-2,757	-2,796	-3,812
Sulfur dioxide (SO_2)					
2018	0	-141	-194	-212	-259
2025	0	-4,065	-6,379	-7,876	-10,685
2035	0	-12,147	-21,495	-22,448	-28,503
2050	0	-16,916	-30,627	-30,910	-38,887
Volatile organic compounds (VOC)					
2018	0	-145	-197	-213	-261
2025	0	-10,832	-16,310	-18,078	-24,295
2035	0	-34,357	-50,406	-51,477	-63,746
2050	0	-49,172	-71,748	-71,974	-87,894

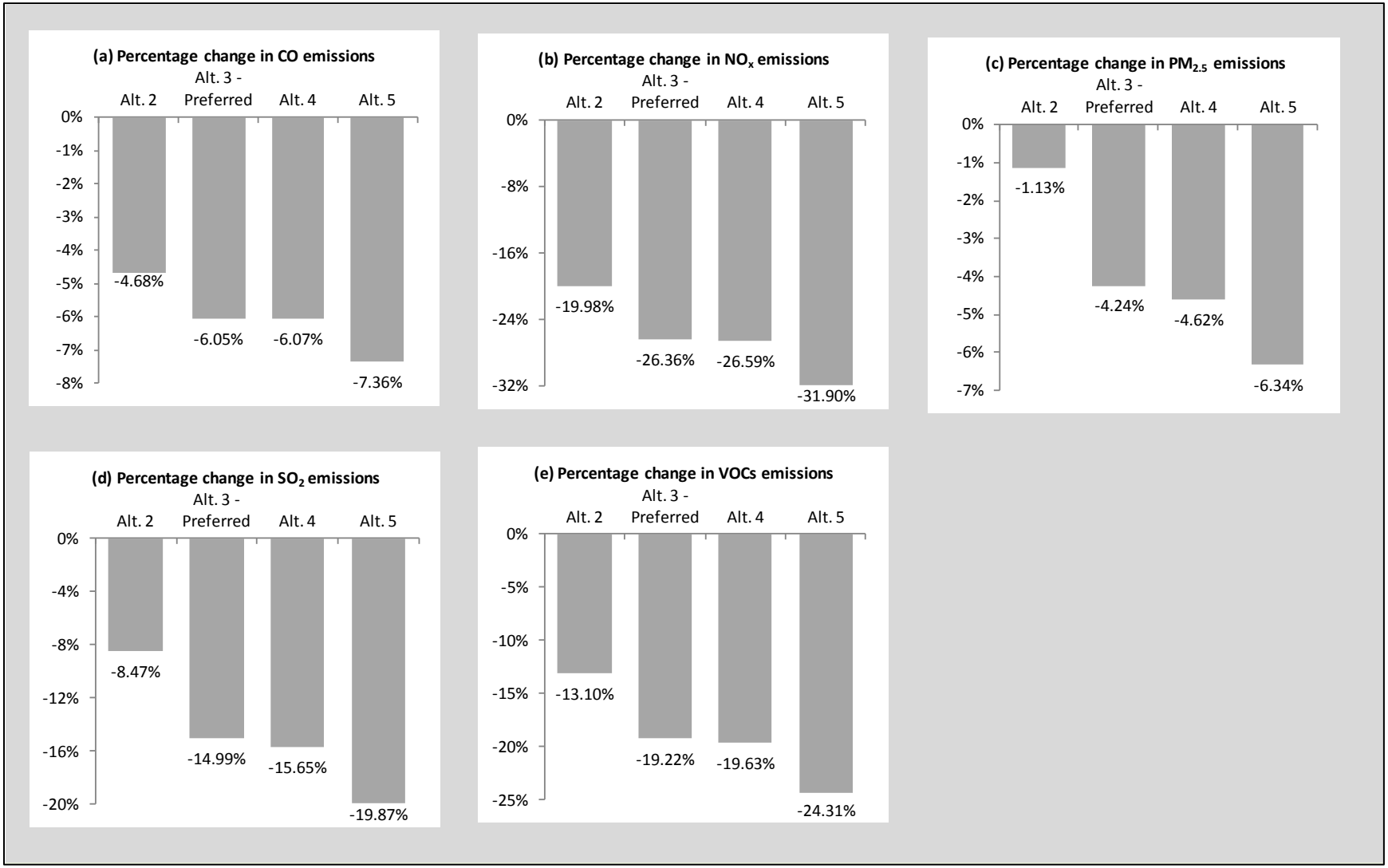
Notes:

[a] Emissions changes are rounded to the nearest whole number.

[b] Negative emissions changes indicate reductions; positive emissions changes are increases.

[c.] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

Figure 4.2.2-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Cumulative Impacts



The differences in national emissions of criteria air pollutants among the action alternatives compared to the No Action Alternative would range from small (less than 1 percent) to large (up to 38 percent) due to the interactions of the multiple factors described above. The small differences are not expected to lead to measurable changes in concentrations of criteria pollutants in the ambient air. The large differences in emissions could lead to changes in ambient pollutant concentrations.

Table 4.2.2-4 summarizes the criteria air pollutant analysis results by nonattainment area. Tables in Appendix A list the emissions changes for each nonattainment area. For CO, Appendix A indicates that most nonattainment areas would experience increases in emissions in 2018 under all the action alternatives, but most would experience decreases in emissions in 2025, 2035, and 2050 under all the action alternatives. For NO_X, most nonattainment areas would experience decreases in emissions across all alternatives and years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under all the action alternatives, but most would experience increases in emissions in 2025, 2035, and 2050 under all the action alternatives. For SO_2 and VOCs, most nonattainment areas would experience decreases in emissions across all alternatives and years.

Table 4.2.2-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Cumulative Impacts

Toxic Air Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area (NAAQS Standard[s])
Carbon monoxide (CO)	Maximum Increase	1	2018	Alt. 2	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-5,870	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA (CO [1971 8-hr]; NO_2 [1971 annual])
Nitrogen oxides (NO_X)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-19,662	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
Particulate matter (PM2.5)	Maximum Increase	80	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-335	2050	Alt. 5	Baton Rouge, LA (Ozone [1997 8-hr]; Ozone [2008 8-hr])
Sulfur dioxide (SO_2)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-2,815	2050	Alt. 5	Beaumont/Port Arthur, TX (Ozone [1997 8-hr])
Volatile organic compounds (VOC)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-3,150	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])

4.2.2.1.2 Toxic Air Pollutants Overview

Table 4.2.2-5 summarizes the total upstream and downstream[32] emissions of toxic air pollutants from HD vehicles by alternative for each of the toxic air pollutants and analysis years. The trends for toxic air pollutant emissions across the alternatives generally show decreases for the same reasons as for criteria pollutants (*see* Section 4.2.2.1.1). These tables show that emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde would generally remain the same or decrease from Alternative 1 to Alternative 5. These trends are accounted for by the extent of technologies assumed to be deployed under the different alternatives to meet the different levels of fuel efficiency requirements.

Table 4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	8,308	8,308	8,308	8,308	8,308
2025	6,568	6,099	5,897	5,896	5,693
2035	6,162	4,630	4,270	4,270	3,910
2050	7,400	5,180	4,718	4,719	4,257
Acrolein					
2018	1,335	1,335	1,335	1,335	1,335
2025	982	914	884	884	855
2035	868	647	595	595	544
2050	1,040	720	654	654	587
Benzene					
2018	3,364	3,363	3,363	3,363	3,363
2025	2,564	2,465	2,419	2,412	2,363
2035	2,287	1,967	1,863	1,858	1,768
2050	2,657	2,195	2,055	2,055	1,937
1,3-Butadiene					
2018	604	604	604	604	604
2025	322	315	313	313	309
2035	180	160	155	155	150
2050	198	170	163	163	157
Diesel particulate matter (DPM)					
2018	136,800	136,766	136,754	136,752	136,740
2025	102,661	102,524	102,202	101,872	101,426
2035	91,559	91,009	89,208	89,001	87,960
2050	109,482	108,726	105,972	105,931	104,542

[32] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Formaldehyde					
2018	21,015	21,015	21,015	21,015	21,015
2025	18,472	16,989	16,353	16,349	15,710
2035	18,742	13,911	12,772	12,771	11,636
2050	22,689	15,690	14,226	14,227	12,770

Figure 4.2.2-4 shows toxic air pollutant emissions for each alternative in 2035, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the Proposed Action.

Figure 4.2.2-5 summarizes the changes over time in total national emissions of toxic air pollutants from HD vehicles under the Preferred Alternative. Figures 4.2.2-4 and 4.2.2-5 indicate a consistent trend among the toxic air pollutants. Emissions decline from 2018 to 2035 due to increasingly stringent EPA regulation of emissions from vehicles and from reductions in upstream emissions from fuel production, but increase from 2035 to 2050 due to continuing growth in VMT.

As with criteria pollutant emissions (*see* Section 4.2.2.1.1), total toxic pollutant emissions are made up of six components, consisting of two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three HD vehicle classes covered by the proposed rule. (Emissions associated with the tractor-trailer classes include effects of proposed trailer standards.) To show the relationship among these six components for toxic air pollutants, Table 4.2.2-6 breaks down the total emissions of air toxic pollutants by component for calendar year 2035.

Table 4.2.2-7 lists the net change in nationwide emissions from HD vehicles for each of the toxic air pollutants and analysis years under the action alternatives compared to the No Action Alternative. Figure 4.2.2-6 shows these changes in percentages for 2035. Together, these tables and figures show that the emissions changes compared to the No Action Alternative tend to increase from 2018 to 2050. For each combination of pollutant and year, the emissions generally remain the same or decrease from Alternative 2 to Alternative 5, reflecting the increasing stringency of the alternatives.

The differences in national emissions of toxic air pollutants among the action alternatives compared to the No Action Alternative range from small (less than 1 percent) to large (up to 44 percent) due to the interactions of the multiple factors described above in Section 4.2.2.1.1. The small differences are not expected to lead to measurable changes in concentrations of toxic air pollutants in the ambient air. For such small changes, the impacts of those action alternatives would be essentially equivalent. The large differences in emissions could lead to changes in ambient pollutant concentrations.

Figure 4.2.2-4. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2035 by Alternative, Cumulative Impacts

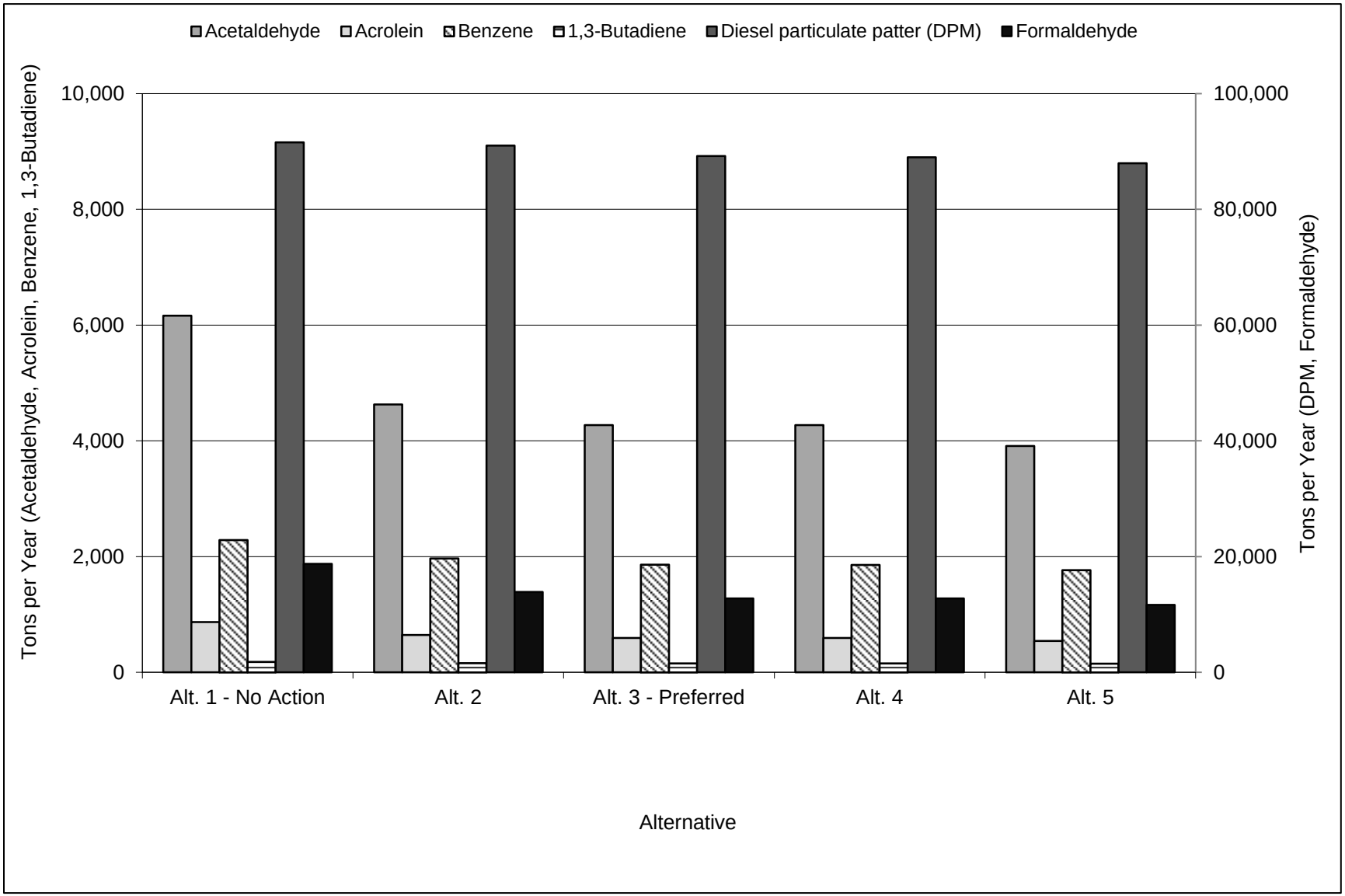


Figure 4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Cumulative Impacts

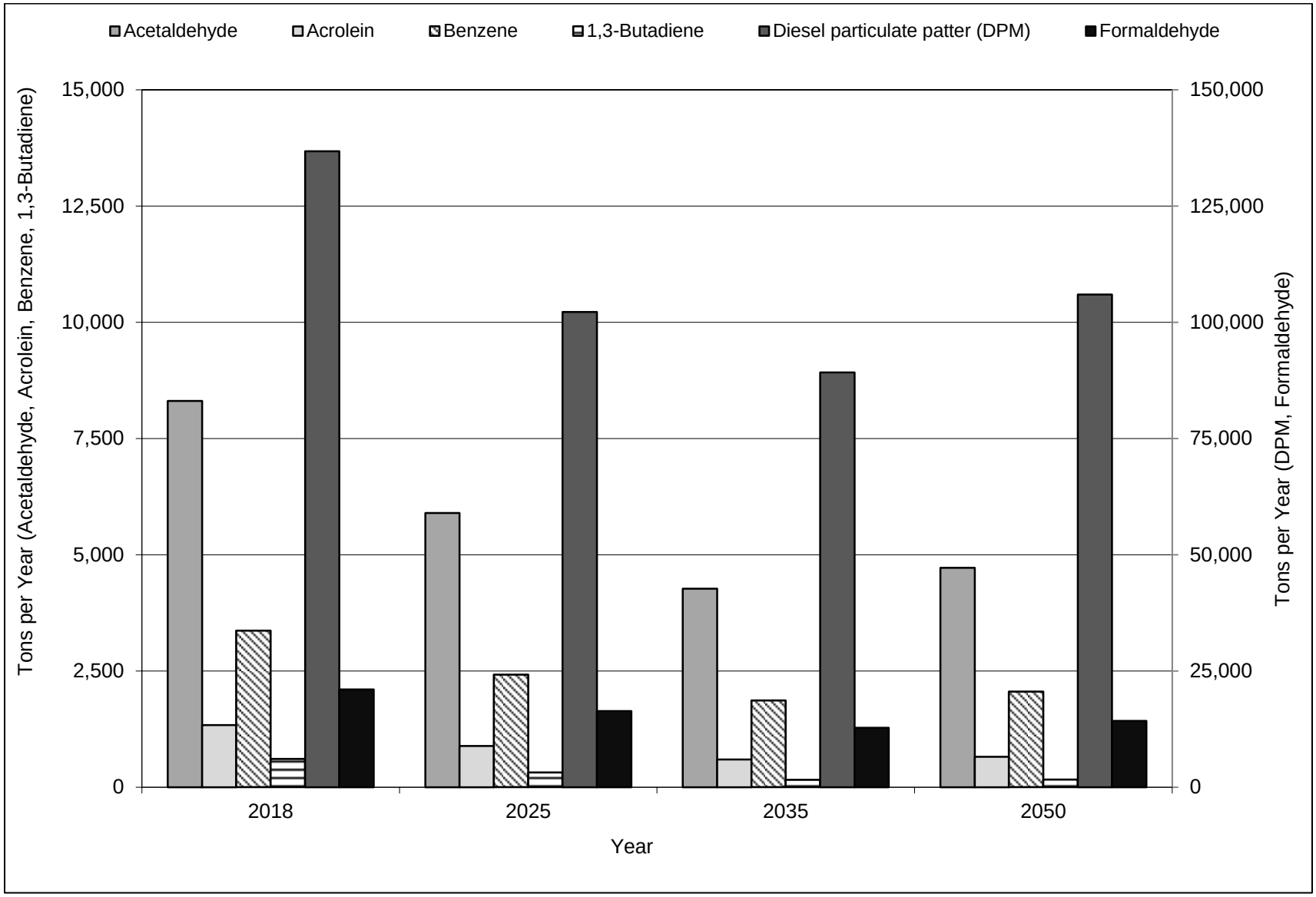


Table 4.2.2-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. HD Vehicles, by Vehicle Type and Alternative, Cumulative Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
Classes 2b–3 Work Trucks Tailpipe	470	473	474	475	475
Classes 2b–3 Work Trucks Upstream	5	5	5	5	4
Classes 3–8 Vocational Vehicles Tailpipe	580	585	585	585	585
Classes 3–8 Vocational Vehicles Upstream	53	52	49	48	46
Classes 7–8 Combination Unit Tailpipe	5,020	3,484	3,129	3,129	2,773
Classes 7–8 Combination Unit Upstream	35	31	29	28	27
Total	6,162	4,630	4,270	4,270	3,910
Acrolein					
Classes 2b–3 Work Trucks Tailpipe	53	54	54	54	54
Classes 2b–3 Work Trucks Upstream	1	1	1	1	1
Classes 3–8 Vocational Vehicles Tailpipe	77	78	78	78	78
Classes 3–8 Vocational Vehicles Upstream	5	5	4	4	4
Classes 7–8 Combination Unit Tailpipe	727	505	454	454	403
Classes 7–8 Combination Unit Upstream	5	4	4	4	4
Total	868	647	595	595	544
Benzene					
Classes 2b–3 Work Trucks Tailpipe	443	445	448	448	449
Classes 2b–3 Work Trucks Upstream	90	84	79	78	76
Classes 3–8 Vocational Vehicles Tailpipe	334	337	335	334	333
Classes 3–8 Vocational Vehicles Upstream	191	188	175	174	164
Classes 7–8 Combination Unit Tailpipe	936	650	584	584	518
Classes 7–8 Combination Unit Upstream	293	262	242	241	227
Total	2,287	1,967	1,863	1,858	1,768
1,3-Butadiene					
Classes 2b–3 Work Trucks Tailpipe	70	70	70	70	70
Classes 2b–3 Work Trucks Upstream	2	2	2	2	2
Classes 3–8 Vocational Vehicles Tailpipe	25	25	25	25	25
Classes 3–8 Vocational Vehicles Upstream	4	4	4	4	4
Classes 7–8 Combination Unit Tailpipe	62	44	40	40	36
Classes 7–8 Combination Unit Upstream	17	15	14	14	13
Total	180	160	155	155	150
Diesel particulate matter (DPM)					
Classes 2b–3 Work Trucks Tailpipe	406	409	410	410	411

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Classes 2b–3 Work Trucks Upstream	2,874	2,683	2,534	2,497	2,448
Classes 3–8 Vocational Vehicles Tailpipe	13,739	13,957	13,953	13,952	13,948
Classes 3–8 Vocational Vehicles Upstream	5,867	5,703	5,305	5,260	4,965
Classes 7–8 Combination Unit Tailpipe	47,916	49,676	49,842	49,821	50,089
Classes 7–8 Combination Unit Upstream	20,757	18,581	17,165	17,060	16,100
Total	91,559	91,009	89,208	89,001	87,960
Formaldehyde					
Classes 2b–3 Work Trucks Tailpipe	992	1,000	1,002	1,003	1,004
Classes 2b–3 Work Trucks Upstream	41	39	37	36	36
Classes 3–8 Vocational Vehicles Tailpipe	1,630	1,647	1,647	1,647	1,647
Classes 3–8 Vocational Vehicles Upstream	93	90	84	83	79
Classes 7–8 Combination Unit Tailpipe	15,695	10,875	9,762	9,763	8,646
Classes 7–8 Combination Unit Upstream	290	260	240	239	225
Total	18,742	13,911	12,772	12,771	11,636

Table 4.2.2-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	0	0	0	0	0
2025	0	-470	-672	-672	-875
2035	0	-1,532	-1,892	-1,892	-2,252
2050	0	-2,220	-2,681	-2,681	-3,142
Acrolein					
2018	0	0	0	0	0
2025	0	-68	-97	-97	-127
2035	0	-221	-273	-273	-324
2050	0	-320	-386	-386	-453
Benzene					
2018	0	0	-1	-1	-1
2025	0	-99	-145	-152	-201
2035	0	-320	-425	-429	-520
2050	0	-462	-602	-602	-720
1,3-Butadiene					
2018	0	0	0	0	0
2025	0	-7	-9	-9	-13
2035	0	-20	-25	-25	-30
2050	0	-28	-35	-35	-41
Diesel particulate matter (DPM)					
2018	0	-35	-47	-49	-60
2025	0	-137	-459	-789	-1,235
2035	0	-550	-2,351	-2,559	-3,599
2050	0	-757	-3,510	-3,552	-4,940
Formaldehyde					
2018	0	1	0	1	0
2025	0	-1,483	-2,119	-2,123	-2,762
2035	0	-4,831	-5,970	-5,971	-7,106
2050	0	-6,999	-8,463	-8,462	-9,919

Notes:

[a.] Emissions changes are rounded to the nearest whole number.

[b.] Negative emissions changes indicate reductions; positive emissions changes are increases.

[c.] Emissions changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which emissions under the other alternatives are compared.

Figure 4.2.2-6 (a)–(f). Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HD Vehicles for 2035 by Action Alternative Compared to the No Action Alternative, Cumulative Impacts

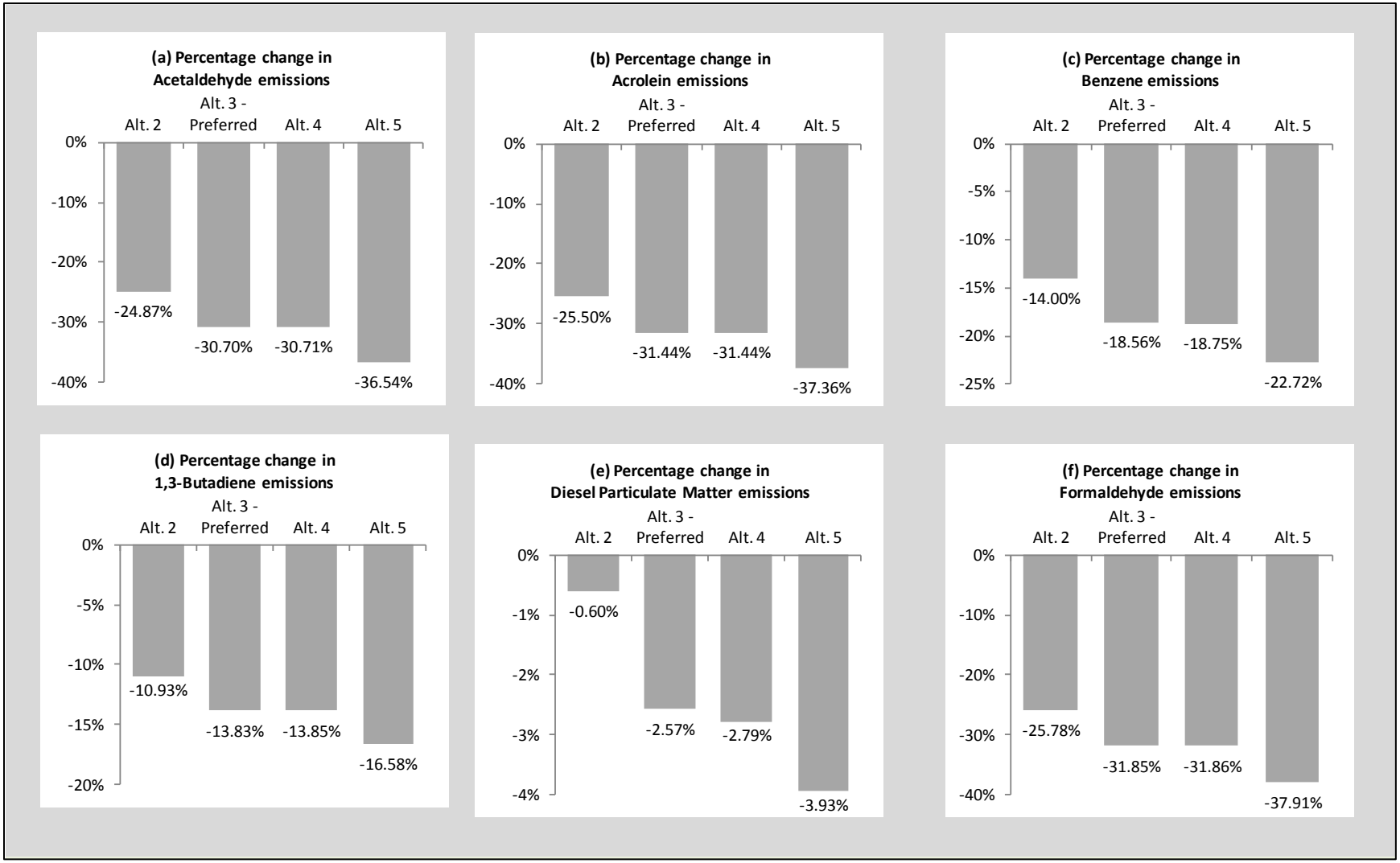


Table 4.2.2-8 summarizes the air toxics analysis results by nonattainment area.[33] Tables in Appendix A list the estimated emissions changes for each nonattainment area. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, Appendix A indicates that most nonattainment areas experience increases in emissions in 2018 under all the action alternatives, but decreases in 2025, 2035, and 2050 under all the action alternatives. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under all the action alternatives. For DPM, most nonattainment areas experience decreases in emissions in 2018 under all the action alternatives, but increases in 2025, 2035, and 2050 under all the action alternatives.

Table 4.2.2-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Cumulative Impacts

Toxic Air Pollutant	Max. Increase/ Decrease	Emissions Change (tons per year)	Year	Alt.	Nonattainment or Maintenance Area (NAAQS Standard[s])
Acetaldehyde	Maximum Increase	< 1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-135	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA (CO [1971 8-hr]; NO_2 [1971 annual])
Acrolein	Maximum Increase	< 1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-19	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
Benzene	Maximum Increase	< 1	2018	Alt. 2	Riverside County; Coachella Valley planning area, CA (PM 10 [1987 24-hr])
	Maximum Decrease	-26	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
1,3-Butadiene	Maximum Increase	< 1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-2	2050	Alt. 5	Houston-Galveston-Brazoria, TX (Ozone [1997 8-hr])
Diesel particulate matter (DPM)	Maximum Increase	101	2050	Alt. 2	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-431	2050	Alt. 5	Baton Rouge, LA (Ozone [1997 8-hr]; Ozone [2008 8-hr])
Formaldehyde	Maximum Increase	< 1	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])
	Maximum Decrease	-424	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT (Ozone [1997 8-hr])

[33] EPA has not established NAAQS for airborne toxics. Therefore, none of these areas is classified as a nonattainment area as a result of airborne toxics emissions. Toxic air pollutant emissions data for nonattainment areas are provided for information only.

4.2.2.1.3 Health Effects and Monetized Health Benefits Overview

Adverse health effects would decrease nationwide under each of the action alternatives compared to the No Action Alternative (*see* Table 4.2.2-9). As described in Section 4.1.2.7.2, the changes in PM mortality shown in these tables are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). While the number of PM mortalities varies between the two methods, the percent change in mortality across alternatives and years is equal. The health benefits across all outcomes remain the same or increase from Alternative 2 to Alternative 5 and from near-future (2018) to later years (2050). For each combination of pollutant and year, the health benefits increase from Alternative 2 to Alternative 5, reflecting the increasing stringency of the alternatives.

Table 4.2.2-9. Nationwide Changes in Health Outcomes (cases per year) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Outcome and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Premature mortality - Krewski et al. (2009)					
2018	0	-2	-3	-3	-4
2025	0	-104	-161	-187	-252
2035	0	-350	-568	-587	-734
2050	0	-496	-812	-817	-1,011
Premature mortality – Lepeule et al. (2012)					
2018	0	-6	-7	-8	-10
2025	0	-236	-364	-426	-574
2035	0	-801	-1,291	-1,334	-1,667
2050	0	-1,135	-1,848	-1,859	-2,296
Acute bronchitis					
2018	0	-4	-5	-6	-7
2025	0	-164	-254	-297	-400
2035	0	-525	-850	-878	-1,098
2050	0	-744	-1,216	-1,223	-1,512
Work-loss days					
2018	0	-343	-453	-487	-602
2025	0	-13,802	-21,332	-24,954	-33,634
2035	0	-42,728	-69,653	-72,025	-90,191
2050	0	-60,474	-99,706	-100,307	-124,165
Emergency room visits – respiratory					
2018	0	-1	-2	-2	-2
2025	0	-54	-83	-97	-130
2035	0	-176	-282	-291	-364
2050	0	-249	-404	-406	-501

Notes:

a. Incidence estimates are rounded to the nearest whole number.

b Negative changes indicate fewer health impacts; positive changes indicate additional health impacts.

c. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

The monetized health benefits follow similar trends to the changes in health outcomes. Table 4.2.2-10 lists the corresponding monetized health benefits under the action alternatives compared to the No Action Alternative. Monetized health benefits are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). Under each action alternative, the monetized health benefits increase from 2018 to 2050. In each analysis year, the monetized health benefits of each action alternative increase from Alternative 2 (least stringent) to Alternative 5 (most stringent).

Table 4.2.2-10. Nationwide Monetized Health Benefits (U.S. million dollars per year, 2012$) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Rate and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
3-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$25	$33	$36	$44
2025	$0	$1,086	$1,677	$1,957	$2,636
2035	$0	$3,912	$6,345	$6,557	$8,204
2050	$0	$5,539	$9,081	$9,135	$11,297
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$57	$76	$82	$101
2025	$0	$2,455	$3,789	$4,422	$5,957
2035	$0	$8,879	$14,334	$14,807	$18,511
2050	$0	$12,578	$20,513	$20,632	$25,494
7-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$23	$30	$33	$40
2025	$0	$977	$1,507	$1,759	$2,369
2035	$0	$3,511	$5,689	$5,879	$7,354
2050	$0	$4,971	$8,142	$8,190	$10,128
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$51	$68	$72	$90
2025	$0	$2,197	$3,393	$3,962	$5,339
2035	$0	$7,992	$12,921	$13,350	$16,693
2050	$0	$11,320	$18,494	$18,602	$22,991

Notes:

a. Monetized health benefits are rounded to the nearest whole number.

b. Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts.

b. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

Sections 4.2.2.2 through 4.2.2.5 describe the results of the analysis of emissions for Alternatives 1 through 5 in more detail. The emissions changes from one alternative to the next compared to the No Action Alternative generally increase, with a few exceptions that are discussed in these sections, between Alternative 2 and Alternative 5 consistent with increases in overall fuel efficiency.

4.2.2.2 Alternative 1 - No Action

4.2.2.2.1 Criteria Pollutants

The No Action Alternative generally assumes no market-based gains in new HD vehicle fuel efficiency after 2018. Current trends in the levels of criteria pollutant emissions from vehicles would continue under the No Action Alternative, with emissions of CO, NO_X, PM2.5, and VOCs continuing to decline due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2035, but increasing from 2035 to 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.2-1 and Figure 4.2.2-1). Emissions of SO_2 under the No Action Alternative are predicted to increase from 2018 to 2050 because declines due to market-based gains in new vehicle HD vehicle fuel efficiency are more than offset by growth in VMT beginning before 2018. The No Action Alternative would not change these trends and therefore would not result in any change in criteria pollutant emissions nationally or in nonattainment areas beyond changes projected to result from future trends in emissions and VMT (*see* Table 4.2.2-1).

Emissions of CO, NO_x, PM2.5, SO_2, and VOCs under the No Action Alternative are greater than emissions under all of the action alternatives. Changes in emissions of all criteria pollutants are generally greatest in 2050 under Alternative 5, in which emissions range up to 38 percent less than under the No Action Alternative.

4.2.2.2.2 Toxic Air Pollutants

EPA regulates toxic air pollutants from motor vehicles through vehicle emissions standards and fuel quality standards, as discussed in Section 4.1.1. As with the criteria pollutants, current trends in the levels of toxic air pollutant emissions from vehicles would continue under the No Action Alternative. Emissions would continue to decline in early years due to the EPA emissions standards (*see* Section 4.1.1) despite a growth in total VMT, reaching a minimum in 2035 (2025 for formaldehyde), but increasing in 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.2-5 and Figure 4.2.2-4). The No Action Alternative would not change the current fuel efficiency standards for HD vehicles and therefore would not result in any change in toxic air pollutant emissions throughout the United States beyond projected trends shown for the No Action Alternative in Table 4.2.2-4.

Emissions of acrolein, acetaldehyde, benzene, 1,3-butadiene, DPM, and formaldehyde under the No Action Alternative are the same as or greater than emissions under all of the action alternatives. Changes in emissions of all toxic air pollutants are greatest in 2050 compared to Alternative 5, in which emissions range up to 44 percent less than under the No Action Alternative.

4.2.2.2.3 Health Outcomes and Monetized Benefits

Under the No Action Alternative, current trends in the levels of criteria pollutant and toxic air pollutant emissions from vehicles would continue, with emissions of most criteria pollutants decreasing initially and then increasing to 2050 due to growth in total VMT, which more than offsets reductions due to the EPA vehicle emissions standards (*see* Section 4.1.1). The human health-related trends would continue (*see* Tables 4.2.2-9 and 4.2.2-10). The No Action Alternative would not result in any additional increase or decrease in human health effects throughout the United States.

4.2.2.3 Alternative 2

4.2.2.3.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 2 compared to the No Action Alternative and the action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2035. Under Alternative 2, nationwide emissions of all criteria pollutants decrease compared to the No Action Alternative. Alternative 2 is the least stringent of all the action alternatives, and the emissions reductions under Alternative 2 are less than those under the Preferred Alternative, Alternative 4, and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 2 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 2, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in emissions in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under Alternative 2, but increases in 2025, 2035, and 2050. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.2.3.2 Toxic Air Pollutants

Table 4.2.2-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 2 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentages for 2035. Compared to the No Action Alternative, Alternative 2 would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Alternative 2 would result in the same or higher emissions than would the other action alternatives.

At the national level, emissions of all toxic air pollutants could decrease under Alternative 2 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 2, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 2. For DPM, most nonattainment areas experience decreases in emissions in 2018 under Alternative 2, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.3.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 2 compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under Alternative 2 would range from a minimum benefit of $23 million per year to a maximum benefit of $12.6 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under Alternative 2 are less than those under the other action alternatives.

4.2.2.4 Alternative 3 - Preferred Alternative

4.2.2.4.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under the Preferred Alternative compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2035. Figure 4.2.2-2 shows criteria pollutant emissions under the Preferred Alternative by year. Under this alternative, emissions of all criteria pollutants decrease compared to the No Action Alternative. This alternative reduces emissions more than Alternative 2. Emissions under the Preferred Alternative are less than under Alternative 2, but greater than under Alternative 4 (except for CO in 2018 and 2050) and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under the Preferred Alternative, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under the Preferred Alternative, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.4.2 Toxic Air Pollutants

Table 4.2.2-7 shows the changes in nationwide emissions of toxic air pollutants under the Preferred Alternative compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-5 shows toxic pollutant emissions under the Preferred Alternative by year. Figure 4.2.2-6 shows these changes in percentage terms for 2035. Compared to the No Action Alternative, the Preferred Alternative would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. The Preferred Alternative would result in the same or lower emissions than would Alternative 2, but the same or higher emissions than would Alternative 4 and Alternative 5 (except that acetaldehyde and formaldehyde emissions are slightly lower than under Alternative 4 in 2050).

At the national level, emissions of all toxic air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under the Preferred Alternative, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under the Preferred Alternative. For DPM, most nonattainment areas experience decreases in emissions in 2018 under the Preferred Alternative, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.4.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under the Preferred Alternative compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to

2050. As shown in Table 4.2.2-10, the monetized health impacts under the Preferred Alternative would range from a minimum benefit of $30 million per year to a maximum benefit of $20.5 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under the Preferred Alternative are greater than those under Alternative 2 but less than those under Alternative 4 and Alternative 5.

4.2.2.5 Alternative 4

4.2.2.5.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2035. Under this alternative, emissions of all criteria pollutants decrease compared to the No Action Alternative. This alternative reduces emissions more than Alternative 2 and the Preferred Alternative (except that CO emissions under Alternative 4 are slightly higher than under the Preferred Alternative in 2018 and 2050). With this exception, emissions under Alternative 4 are less than under Alternative 2 and the Preferred Alternative, but greater than under Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 4, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under the Preferred Alternative, but increases in emissions in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.5.2 Toxic Air Pollutants

Table 4.2.2-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentage terms for 2035. Compared to the No Action Alternative, Alternative 4 would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Alternative 4 would result in the same or lower emissions than would Alternative 2 and the Preferred Alternative (except that acetaldehyde and formaldehyde emissions are slightly higher than under the Preferred Alternative in 2050), but the same or higher emissions than would Alternative 5.

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 4, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 4. For DPM, most nonattainment areas experience decreases in emissions in 2018 under Alternative 4, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.5.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 4 compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under Alternative 4 would range from a minimum benefit of $33 million per year to a maximum benefit of $20.6 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 4 are greater than those under Alternative 2 and the Preferred Alternative, but less than those under Alternative 5.

4.2.2.6 Alternative 5

4.2.2.6.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2035. Under this alternative, emissions of all criteria pollutants decrease compared to the No Action Alternative. This alternative reduces emissions more than Alternative 2, the Preferred Alternative, and Alternative 4. Emissions under Alternative 5 are less than under Alternative 2, the Preferred Alternative, and Alternative 4.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 5, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2035, and 2050. For NO_x, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. For PM2.5, most nonattainment areas would experience decreases in emissions in 2018 under Alternative 5, but increases in emissions in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.6.2 Toxic Air Pollutants

Table 4.2.2-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentage terms for 2035. Compared to the No Action Alternative, Alternative 5 would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Alternative 5 would result in the same or lower emissions than would Alternative 2, the Preferred Alternative, and Alternative 4.

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 5, but decreases in 2025, 2035, and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 5. For DPM, most nonattainment areas experience decreases in emissions in 2018 under Alternative 5, but increases in 2025, 2035, and 2050 (*see* Appendix A).

4.2.2.6.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 5 compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under Alternative 5 would range from a minimum benefit of $40 million per year to a maximum benefit of $25.5 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 5 are greater than those under Alternative 2, the Preferred Alternative, and Alternative 4.

CHAPTER 5 GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

This section describes how the Proposed Action would affect the anticipated pace and extent of future changes in global climate. Although the Council on Environmental Quality (CEQ) released revised draft guidance on consideration of the effects of climate change and greenhouse gas (GHG) emissions under the National Environmental Policy Act (NEPA) in December 2014, the revised draft guidance has not been finalized. There is currently no applicable final guidance or regulation from CEQ or U.S. Department of Transportation (DOT) for addressing climate change in an EIS. One of the key matters about which federal agencies must use their own judgment is when they determine how to describe the potential differences between direct and indirect climate change-related impacts of a Proposed Action and the cumulative impacts associated with a Proposed Action.

In this EIS, the discussion of climate change direct and indirect impacts focuses on impacts associated with reductions in GHG emissions due to NHTSA's Proposed Action (assumed to remain in place after 2027 at the level of the Phase 2 standards set forth by the agency), including Alternative 1 (No Action Alternative) and Alternatives 2 through 5the (the action alternatives). The Proposed Action would affect fuel consumption and emissions attributable to commercial medium- and heavy-duty on-highway vehicles and work trucks, hereinafter referred to collectively as *HD vehicles*, into the future. Results in this chapter are shown through 2100, the end of the analytical period for this section. The discussion of consequences of the Proposed Action focuses on GHG emissions and their impacts on the climate system (i.e., atmospheric CO_2 concentrations, temperature, sea level, and precipitation).

The cumulative impacts analysis addresses the effects of the Proposed Action together with those of other past, present, and reasonably foreseeable future actions. These reasonably foreseeable future actions, beyond those resulting directly or indirectly from the Proposed Action, would have additional impacts on fuel consumption and emissions attributable to HD vehicles through 2100. Climate modeling for the cumulative impacts analysis applies different assumptions about the effect of broader global GHG policies on emissions outside the U.S. HD vehicle fleet. The analysis of cumulative impacts also extends the discussion of consequences to include not only the immediate effects of GHG emissions on the climate system (i.e., atmospheric CO_2 concentrations, temperature, sea level, and precipitation) but also the impacts of changes in the climate system on key resources (e.g., freshwater resources, terrestrial ecosystems, and coastal ecosystems).

This chapter is organized as follows.

- **Section 5.1** introduces key topics on GHGs and climate change.
- **Section 5.2** describes the affected environment in terms of current and anticipated trends in GHG emissions and climate.
- **Section 5.3** outlines the methodology NHTSA used to evaluate climate effects.
- **Section 5.4** describes the potential direct, indirect, and cumulative environmental impacts of the Proposed Action and alternatives that NHTSA considered.
- **Section 5.5** qualitatively describes the potential cumulative impacts of climate change on key natural and human resources.
- **Section 5.6** qualitatively describes the potential cumulative non-climate effects of CO_2.

5.1 Introduction

This EIS draws primarily on newly released panel-reviewed synthesis and assessment reports from the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Global Change Research Program (GCRP), supplemented with past reports from the U.S. Climate Change Science Program, the National Research Council, and the Arctic Council. It also cites EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act* (EPA 2009), which relied heavily on past major international or national scientific assessment reports. NHTSA similarly relies on assessment reports because these reports assess numerous individual studies to draw general conclusions about the state of science; are reviewed and formally accepted by, commissioned by, or in some cases authored by U.S. government agencies and individual government scientists; and in many cases reflect and convey the consensus conclusions of expert authors. These sources have been vetted by both the climate change research community and by the U.S. government and are the foundation for the discussion of climate change in this EIS.

To provide the most current review of climate change science, this EIS also draws on peer-reviewed panel reports and literature that have been published since the release of the IPCC and the GCRP panel-reviewed reports. Because the recent peer-reviewed literature has not been assessed or synthesized by an expert panel, these sources supplement, but do not supersede, the findings of the panel-reviewed reports. In virtually every case, the recent literature corroborates the findings of the panel reports.

The level of detail regarding the science of climate change in this EIS, as well as NHTSA's consideration of other studies that demonstrate the potential impacts of climate change on health, society, and the environment, is provided to help inform the public and decisionmakers and is consistent with NHTSA's approach in its EISs for the MY 2012–2016 CAFE standards, MY 2014–2018 HD vehicle standards, and MY 2017–2025 CAFE standards.

5.1.1 Uncertainty within the IPCC Framework

As with all other environmental impacts, assessing climate change impacts involves uncertainty. The CEQ regulations in section 1502.22 require agencies to make clear for potentially significant adverse environmental impacts any incomplete or unavailable information regarding that impact. Similarly, given the global importance of climate change and the need to communicate uncertainty to a variety of decisionmakers, IPCC has focused considerable attention on developing a systematic approach to characterize and communicate this information. In this EIS, NHTSA uses the system developed by IPCC to describe uncertainty associated with various climate change impacts. Consequently, the meanings of these IPCC terms, as further explained below, is different from the language used to describe uncertainty elsewhere in the EIS.

The IPCC reports communicate uncertainty and confidence bounds using commonly understood, but carefully defined, words in italics, such as *likely* and *very likely*, to represent likelihood of occurrence. The *IPCC Working Group 1 (WG1) Fifth Assessment Report (AR5) Summary for Policymakers* (IPCC 2013a) briefly explains this convention. The IPCC Guidance Notes for Lead Authors of the *IPCC AR5 on Addressing Uncertainties* (IPCC 2010) provides a more detailed discussion of the IPCC treatment of uncertainty.

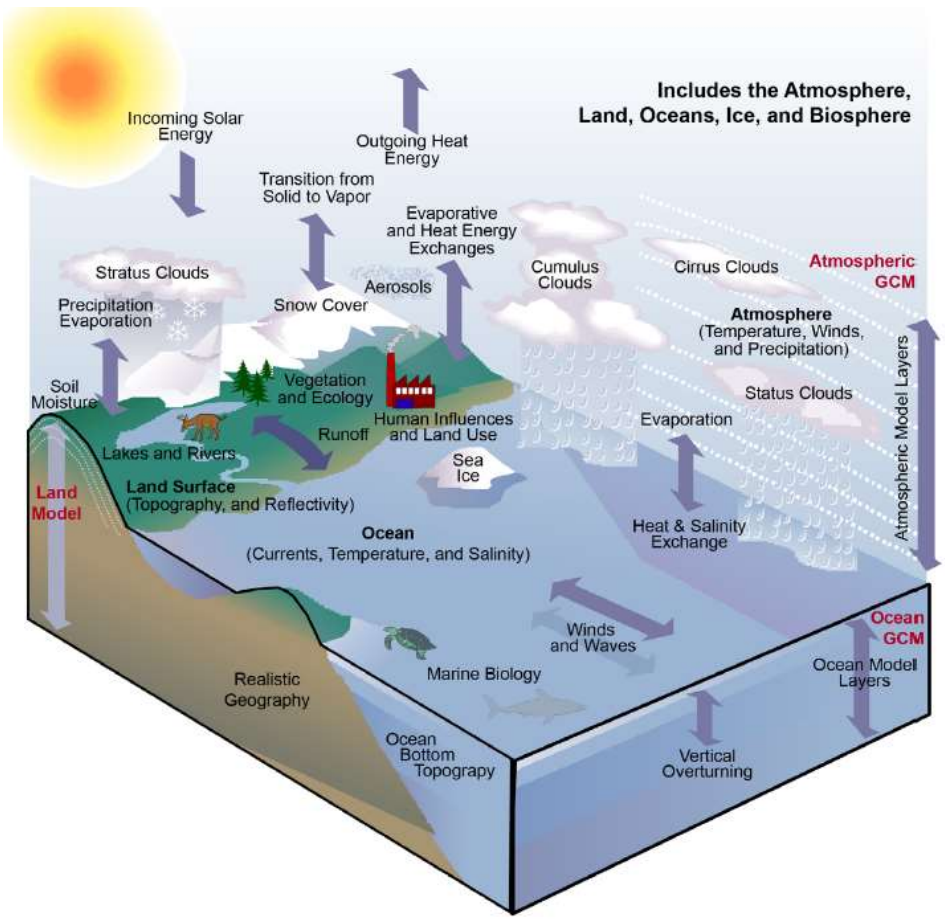
This EIS uses the IPCC uncertainty language (always noted in italics) throughout Chapter 5 when discussing qualitative environmental impacts on specific resources. The reader should refer to the referenced IPCC documents to gain a full understanding of the meaning of those uncertainty terms in the context of the IPCC findings.

The IPCC WG1 AR5: The Physical Science Basis notes that the two primary uncertainties with climate modeling are model uncertainties and scenario uncertainties.

- **Model uncertainties** occur when a climate model might not accurately represent complex phenomena within the climate system (*see* Figure 5.1.1-1 for a sample of processes generally represented in climate models). For some processes, the scientific understanding could be limited regarding how to use a climate model to "simulate" processes within the climate system. Model uncertainties can be differentiated into parametric and structural uncertainties. Parametric uncertainties are a result of uncertainties in the values of model parameters (e.g., the interaction of particles in Earth's atmosphere with water vapor to trigger cloud formation is represented by a parameterization, as opposed to including the very fine-scaled physics within the climate model). Structural uncertainties are the uncertainties that result from incomplete scientific understanding of the processes.
- **Scenario uncertainties** arise because of uncertainty in projecting future GHG emissions, concentrations, and forcings.

As stated in the *IPCC WG1 AR5*, these types of uncertainties are described by using two metrics for communicating the degree of certainty: (1) confidence in the validity of finding, expressed qualitatively, and (2) quantified measures of uncertainties, expressed probabilistically.

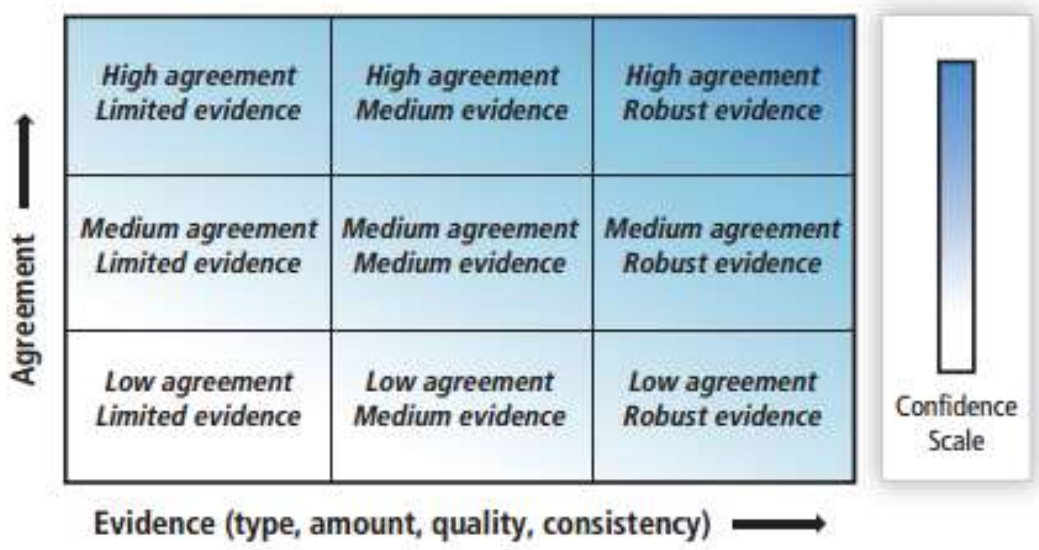
Figure 5.1.1-1. Some of the Climate System Processes Included in Climate Models



Source: GCRP 2014.

The confidence levels synthesize the judgments about the validity of the findings, determined through evaluation of the evidence and the degree of scientific agreement. For qualitatively expressed confidence, the range in assigning confidence is from *very low* to *very high*, with higher confidence levels assigned to findings that are supported by high scientific agreement. For quantitatively expressed confidence, the range in assigning confidence is from *exceptionally unlikely* to *virtually certain*, with higher confidence representing findings supported by robust evidence. Figure 5.1.1-2 shows the degree of confidence for both metrics. Confidence increases diagonally from bottom left to top right.

Figure 5.1.1-2. The Basis for the Confidence Level Given as a Combination of Evidence and Agreement



Source: IPCC 2013b

Table 5.1.1-1 identifies the terms that the IPCC uses to define the likelihood of an occurrence or outcome (where the outcome or result can be estimated probabilistically). The IPCC has defined the list of terms to be used to indicate the assessed likelihood.

Table 5.1.1-1. Standard Terms Used to Define the Likelihood of an Occurrence of a Climate-related Event

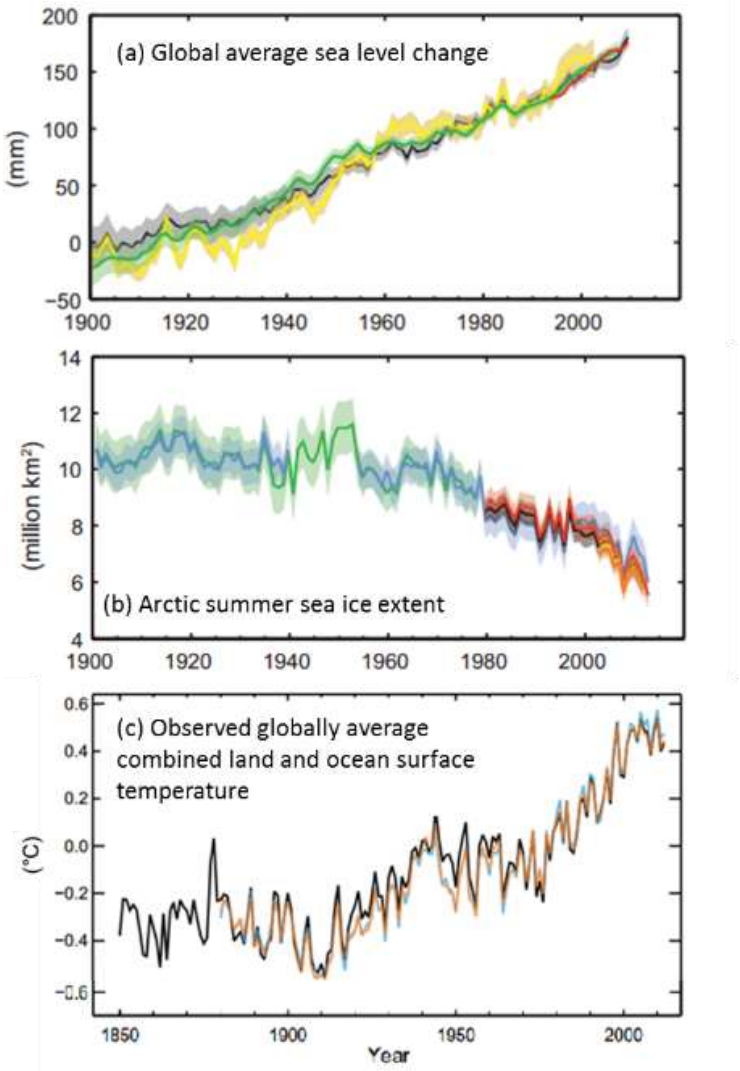
Likelihood Terminology	Likelihood of the Occurrence/Outcome
Virtually certain	99%–100% probability
Very likely	90%–100% probability
Likely	66%–100% probability
About as likely as not	33%–66% probability
Unlikely	0%–33% probability
Very unlikely	0%–10% probability
Exceptionally unlikely	0%–1% probability

Notes:
Source: IPCC 2013b.

5.1.2 Climate Change and Its Causes

Global climate change refers to long-term (i.e., multi-decadal) trends in global average surface temperature, precipitation, ice cover, sea level, cloud cover, sea-surface temperatures and currents, and other climatic conditions. From 1880 to 2012, Earth's global average surface temperature rose by more than 0.8°C (1.4°F) (IPCC 2013a, GCRP 2014). Global mean sea level rose about 19 centimeters (7.5 inches) from 1901 to 2010. From 1901 to 2010, sea levels increased at a rate of 1.7 millimeters (0.07 inch) per year. The rate at the end of this period was much higher, at approximately 3.2 millimeters (0.13 inch) per year from 1993 to 2010 (IPCC 2013a). The annual mean Arctic sea-ice cover has been decreasing at a *very likely* rate of approximately 3.5 to 4.1 percent per decade since 1979, with the summer experiencing a *very likely* faster decrease of 9.4 to 13.6 percent per decade. There is *high* confidence that the extent and volume of mountain glaciers and the Northern Hemisphere snow cover have been decreasing (IPCC 2014). Figure 5.1.2-1 shows changes in sea level, arctic sea ice, and surface temperatures.

Figure 5.1.2-1. The Basis for the Confidence Level Given as a Combination of Evidence and Agreement



Source: IPCC 2013a.

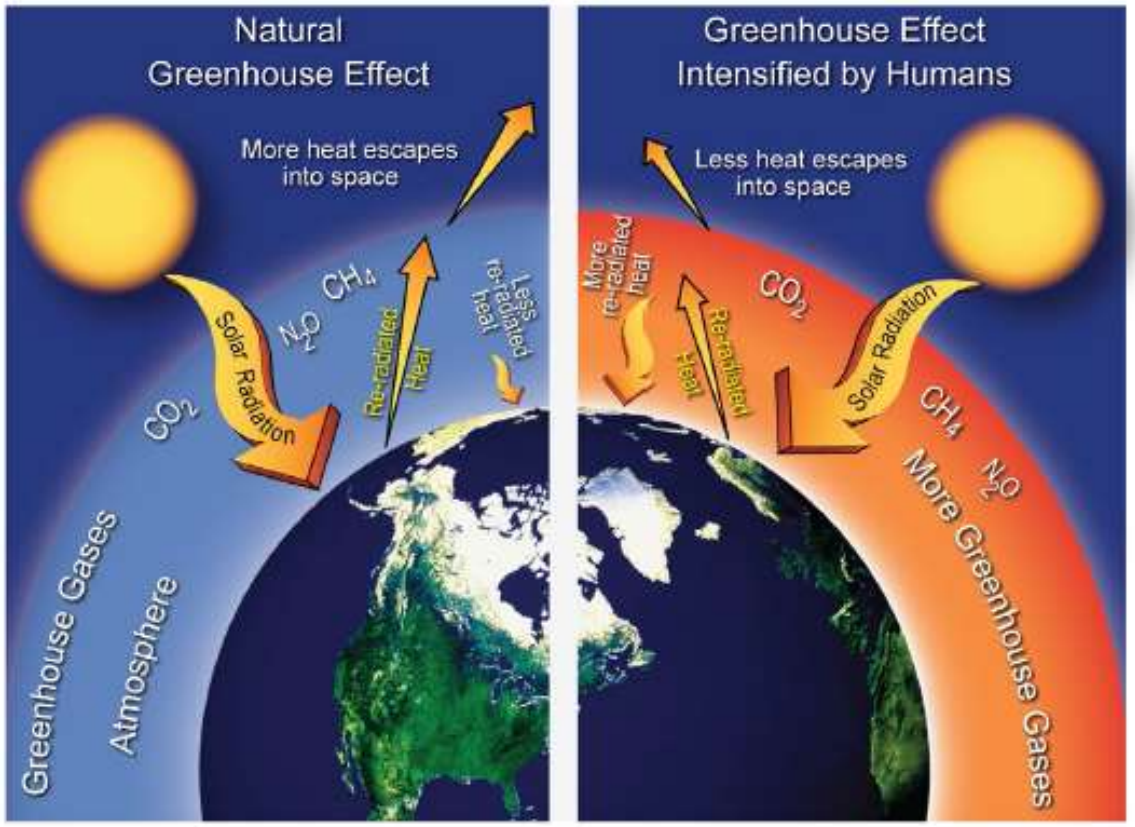
Note: Each line on the graphs above depicts mean values of one data set. Multiple data sets are displayed in each graph using different colors. Shaded areas in the graphs depict uncertainty in the data sets.

For the United States (GCRP 2014):

- U.S. annual average temperature has increased by 1.3°F to 1.9°F since 1895, and most of this increase has occurred since 1970.
- There is ample evidence that sea-surface temperatures have risen throughout the North Atlantic and Pacific Ocean regions by more than 0.9°F since 1900.
- U.S. average annual precipitation has increased by approximately 5 percent, but some areas have had increases greater than the national averages, and some areas have had decreases.

Earth absorbs heat energy from the sun and returns most of this heat to space as terrestrial infrared radiation. GHGs trap heat in the lower atmosphere (the atmosphere extending from Earth's surface to approximately 4 to 12 miles above the surface), absorb heat energy emitted by Earth's surface and lower atmosphere, and reradiate much of it back to Earth's surface, thereby causing warming. This process, known as the *greenhouse effect*, is responsible for maintaining surface temperatures that are warm enough to sustain life (*see* Figure 5.1.2-2). Human activities, particularly fossil-fuel combustion, lead to the presence of increased concentrations of GHGs in the atmosphere; this buildup of GHGs is changing Earth's energy balance (*see* Figure 5.1.2-2). Climate simulations support this finding by demonstrating that the warming experienced over the past century requires the inclusion of both natural GHGs and other climatic forcers (e.g., solar activity) as well as manmade climate forcers.

Figure 5.1.2-2. Human Influence on the Greenhouse Effect



Source: GCRP 2014.

The observed changes in the global climate described in Section 5.2 are largely a result of GHG emissions from human activities. The IPCC has concluded that "[H]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in

global mean sea-level rise, and in changes in some climate extremes. This evidence for human influence has grown since the IPCC *Fourth Assessment Report* (AR4). It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013a).

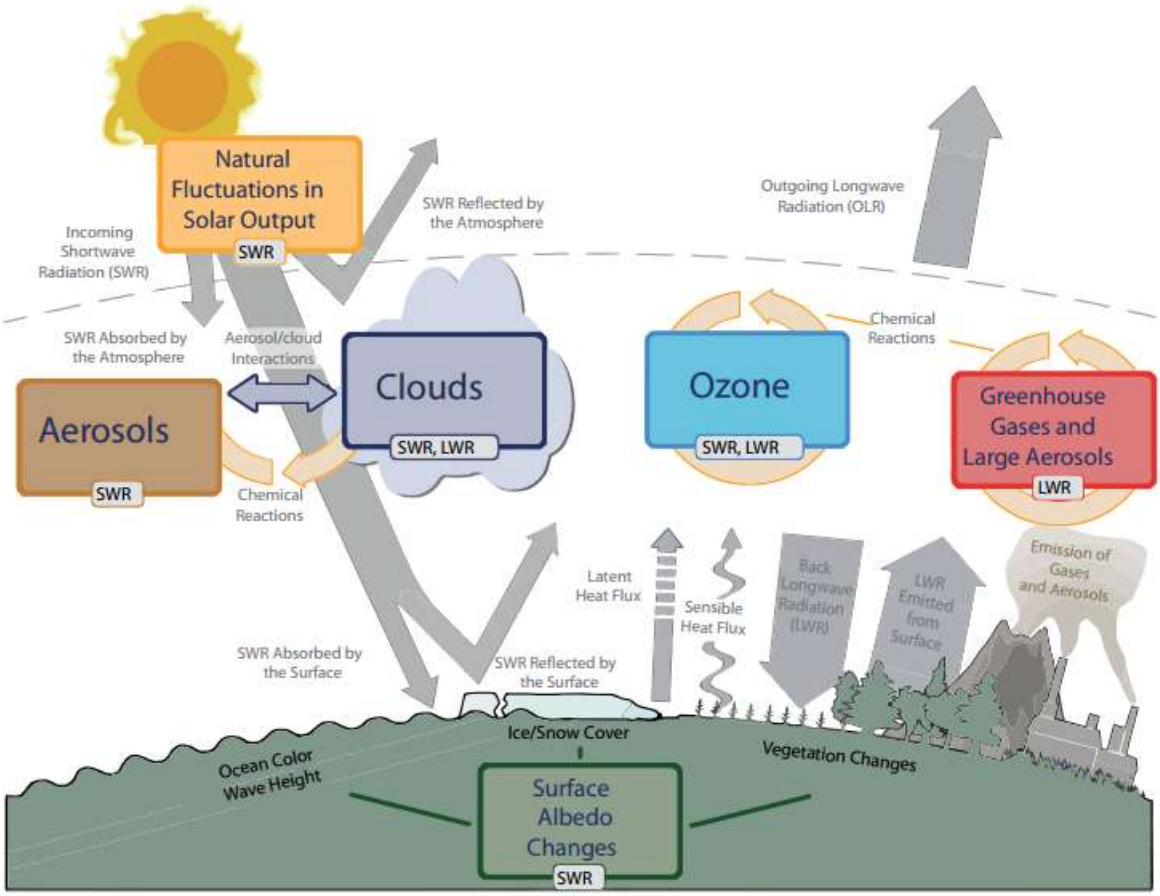
5.1.2.1 Main Drivers of Climate Change

Though the climate system is complex, scientists have identified main drivers that lead to changes in climate (*see* Figure 5.1.2-3). These include the following:

- **GHGs**: Gaseous constituents found within the atmosphere, both natural and anthropogenic, that absorb and emit terrestrial infrared radiation. Primary GHGs found in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone (IPCC 2013a).
- **Aerosols**: Natural and manmade particles in Earth's atmosphere scatter incoming sunlight back to space, causing cooling. Some species are hygroscopic (i.e., attract water) and can affect the formation and lifetime of clouds. Large aerosols (more than 2.5 micrometers [µm] in size) modify the amount of outgoing long-wave radiation (IPCC 2013a). Other particles, such as black carbon, can absorb outgoing terrestrial radiation, causing a warming.
- **Clouds**: Depending on cloud height, cloud interactions with terrestrial and solar radiation can vary. Further, small changes in the properties of clouds can have important implications for both the transfer of radiative energy and weather (IPCC 2013a).
- **Ozone**: A GHG created through photochemical reactions from natural and manmade gases. Ozone in the troposphere is a GHG that absorbs and reemits long-wave radiation. Ozone in the stratosphere, known as the ozone layer, absorbs incoming short-wave radiation (IPCC 2013a).
- **Solar Radiation**: The amount of solar energy that reaches the top of Earth's atmosphere can vary over time (IPCC 2013a).
- **Surface Changes**: Changes in vegetation or land surface properties, ice or snow cover, and ocean color can affect surface albedo (i.e., the fraction of solar radiation that will be reflected by a surface or object). The changes are driven by natural seasonal and diurnal changes (e.g., snow cover) as well as human influences (e.g., changes in vegetation type) (IPCC 2013a).

Most GHGs, including CO_2, CH_4, N_2O, water vapor, and ozone, occur naturally. Human activities such as the combustion of fossil fuel for transportation and electric power can contribute to very substantial increases in the concentrations of these gases in the atmosphere. In addition, a few very potent anthropogenic GHGs, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3), are almost entirely anthropogenic in origin. These gases are produced mainly for use in industrial processes and emitted to the atmosphere (e.g., as a result of leaks in refrigeration and air-conditioning systems).

Figure 5.1.2-3. Main Drivers of Climate Change



Source: IPCC 2013b.

5.1.3 Anthropogenic Sources of Greenhouse Gases

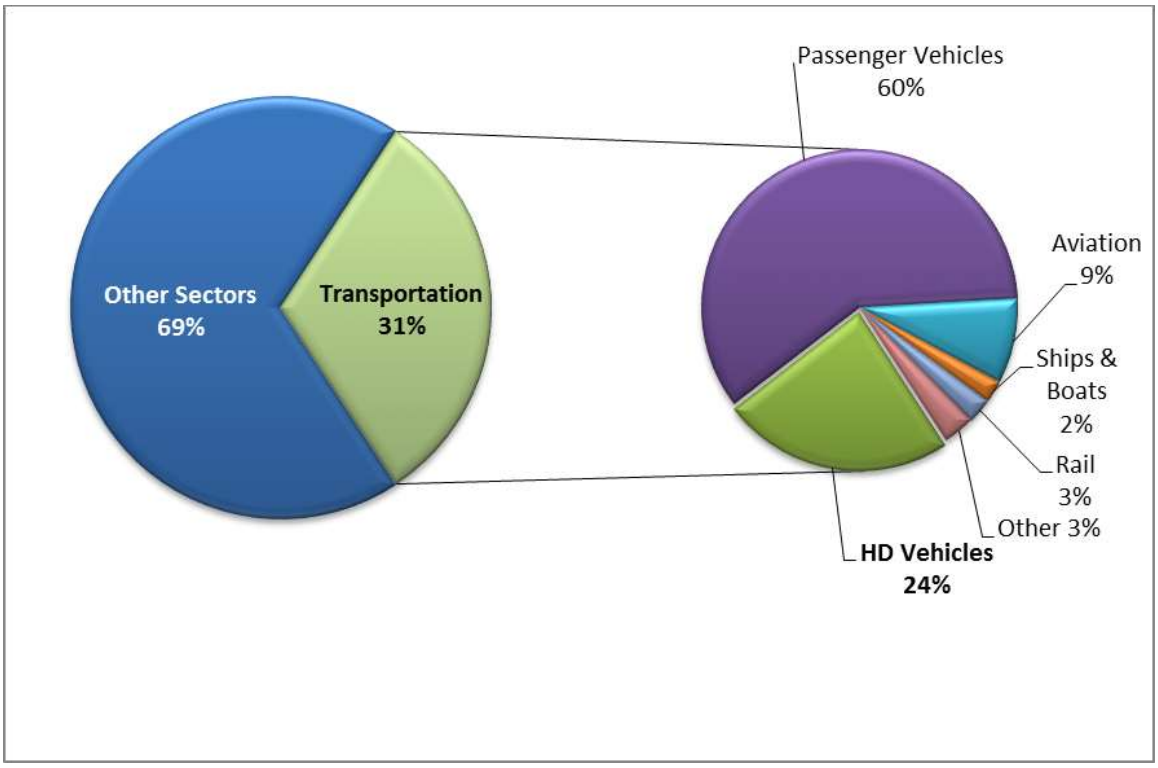
Human activities that emit GHGs to the atmosphere include fossil fuel production and combustion; industrial processes and product use; agriculture, forestry, and other land uses; and waste management. Emissions of CO_2, CH_4, and N_2O from human activities comprise approximately 98 percent of annual anthropogenic GHG emissions addressed by national inventory reports (WRI 2015).[1] Atmospheric concentrations of CO_2, CH_4, and N_2O had, by 2011, increased approximately 40, 150, and 20 percent, respectively, since the beginning of the Industrial Revolution in the mid-1700s (IPCC 2013a). The global atmospheric CO_2 concentration has increased from approximately 278 parts per million (ppm) in 1750 (IPCC 2013b) to approximately 397 ppm in 2014 (NOAA 2015). Isotopic- and inventory-based studies make clear that this rise in the CO_2 concentration is largely a result of the release of carbon that has been stored underground through the combustion of fossil fuels (coal, petroleum, and natural gas) used to produce electricity, heat buildings, and power motor vehicles and airplanes, among other uses.

Contributions to the buildup of GHGs in the atmosphere vary greatly from country to country and depend heavily on the level of industrial and economic activity, population, standard of living, character of a

[1] Each GHG has a different level of radiative forcing (the ability to trap heat). To compare their relative contributions, gases are converted to carbon dioxide equivalent (CO2e) using their unique GWP.

country's buildings and transportation system, available energy options, and climate. According to the World Resources Institute Climate Analysis Indicators Tool (CAIT), emissions from the United States account for approximately 16.5 percent of total global CO_2 emissions (WRI 2015).[2] EPA's National Greenhouse Gas Inventory for 1990 to 2013 indicates that in 2013, the U.S. transportation sector contributed about 31.2 percent of total U.S. CO_2 emissions, with HD vehicles accounting for 23.9 percent of total U.S. CO_2 emissions from transportation (EPA 2015). Therefore, approximately 7.5 percent of total U.S. CO_2 emissions are from HD vehicles, and these vehicles in the United States account for 1.2 percent of total global CO_2 emissions (based on comprehensive global CO_2 emissions data available for 2011).[3] Figure 5.1.3-1 shows the proportion of U.S. emissions attributable to the transportation sector and the contribution of each mode of transportation to U.S. emissions.

Figure 5.1.3-1. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2013



Source: EPA 2015.

5.1.4 Evidence of Climate Change

Observations and studies reporting trends from around the world demonstrate that Earth is undergoing climatic change much more quickly than would be expected from natural variations. As stated in the Third National Climate Assessment (GRCP 2014), "Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans…Taken together, this evidence tells an unambiguous story:

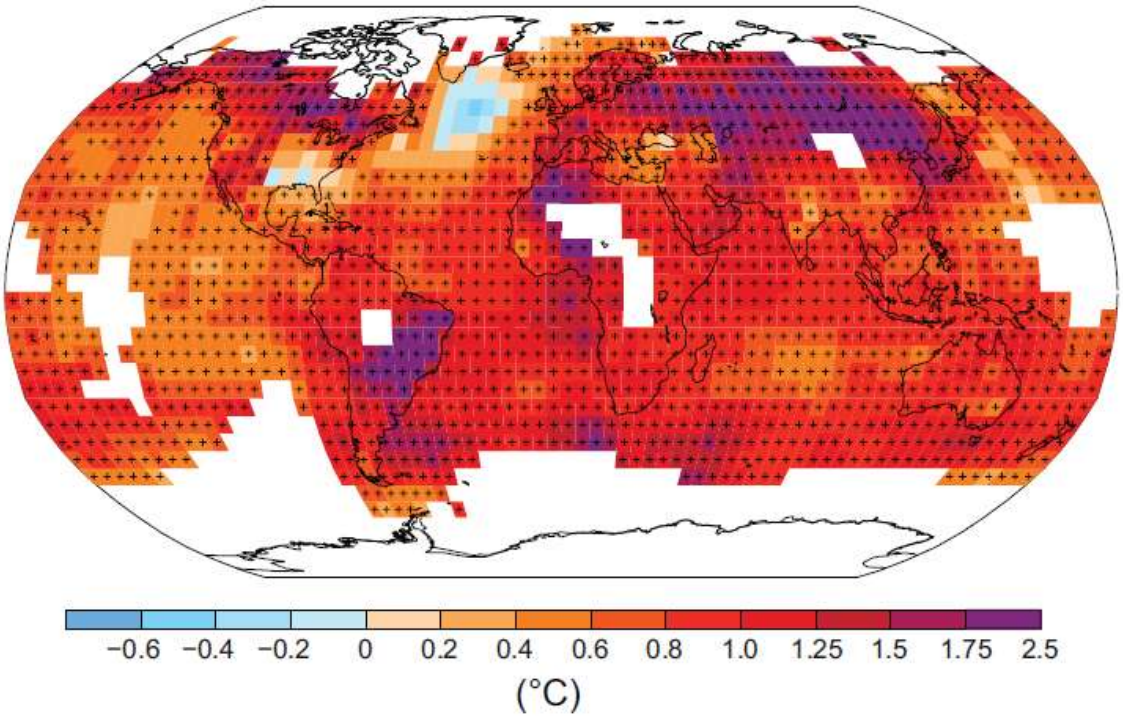
[2] The estimate for global emissions from WRI is for 2011, the most recent year with available data for all GHGs. It excludes emissions and sinks from land use change and forestry.

[3] Percentages exclude land use change and forestry as well as international bunker fuels (i.e., international marine and aviation travel).

the planet is warming, and over the last half century, this warming has been driven primarily by human activity."

The global average surface temperature is rising, with many regions across the globe experiencing more than a 0.4°C (0.7°F) warming since 1901 (IPCC 2013a). The last decade has been the warmest on record, and 2012 was the hottest year on record in the continental United States (GCRP 2014) (*see* Figure 5.1.4-1, below).

Figure 5.1.4-1. Observed Surface Temperature Change from 1901 to 2012[a]



[a] Derived from temperature trends determined by linear regression (IPCC 2013a).

A number of trends observed over the 20th century further support the evidence of climate-induced changes, for example:

- Most land areas have *very likely* experienced warmer and/or fewer cold days and nights along with warmer and/or more frequent hot days and nights (IPCC 2014a).
- Cold-dependent habitats are shifting to higher altitudes and latitudes, and growing seasons are becoming longer (GCRP 2014, IPCC 2014a).
- Sea level is rising, caused by thermal expansion of the ocean and melting of snow and ice (IPCC 2013a).
- More frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (GCRP 2014, IPCC 2013a).
- Oceans are becoming more acidic as a result of increasing absorption of CO_2 by seawater, which is driven by a higher atmospheric concentration of CO_2 (GCRP 2014, IPCC 2013a). Recent evidence suggests with *high confidence* that oceans have become about 26 percent more acidic since the Industrial Revolution (IPCC 2013a).

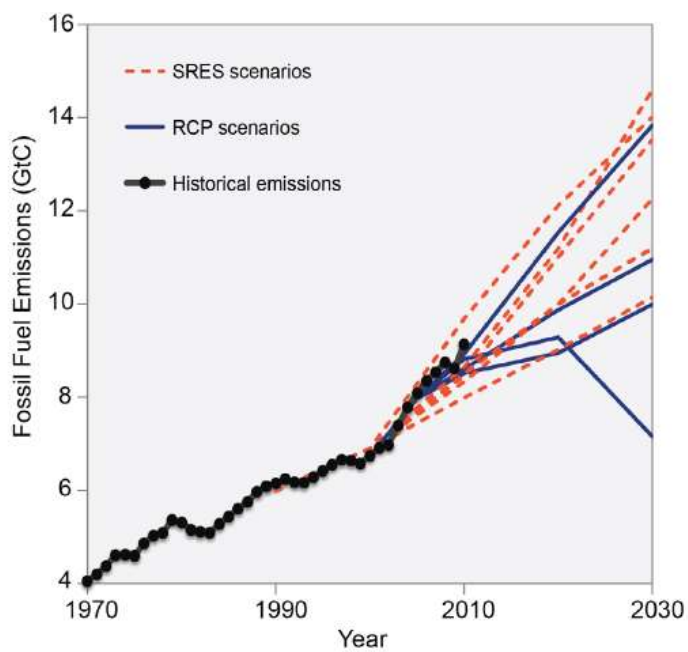
The weight of evidence that climate change is already occurring supports the projections of incremental environmental changes in the future. As discussed later in this chapter, although NHTSA has quantified the impacts of the alternatives on several climate parameters, it is very difficult to translate these changes to damages on specific resources quantitatively. Nonetheless, it is clear from current trends that these resources are likely to be affected to some degree by climate change.

This section provides a qualitative analysis of these trends, which is useful for the decisionmaker in consideration of the projected impacts of the Proposed Action. As discussed below, each of the action alternatives would, to a greater or lesser extent, result in decreased GHG emissions compared with the No Action Alternative. The more the alternatives would reduce GHG emissions, the more they would be expected to also reduce the direct and indirect risks associated with these phenomena. Additional evidence of climate change is discussed throughout this section.

5.1.5 Future Climatic Trends and Expected Impacts

As the world population grows over the 21st century, accompanied by industrialization and increases in living standards in developing countries, fossil-fuel use and resulting GHG emissions are expected to grow substantially, unless there is a substantial shift away from deriving energy from fossil fuels. Based on the current trajectory, the IPCC projects that the atmospheric CO_2 concentration could rise to more than three times pre-industrial levels by 2100 (IPCC 2013b). The effects of the CO_2 emissions that have accumulated in the atmosphere prior to 2100 will persist well beyond 2100. If current trends continue, this elevation in atmospheric CO_2 concentrations will persist for many centuries, with the potential for temperature anomalies continuing much longer (IPCC 2013b). In addition, global GHG emissions since 2000 have been increasing at a growth rate nearly three times greater than that of the 1990s (IPCC 2013b). Comparing observed carbon emissions to projected emissions, the current trajectory is similar to the most fossil fuel-intensive emissions scenario (A1Fi) in the *IPCC Special Report on Emissions Scenarios* (2000) and the highest (RCP8.5) emissions scenario represented by the more recent Representative Concentration Pathways (RCP) (IPCC 2013b) (*see* Figure 5.1.5-1).

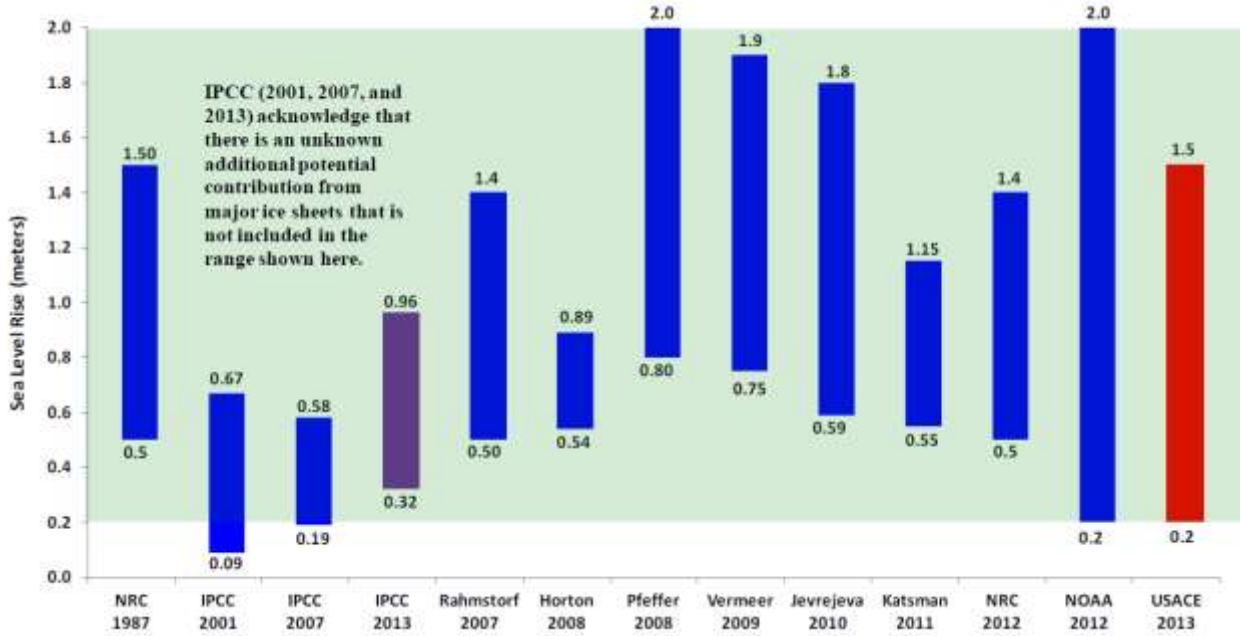
Figure 5.1.5-1. Historical and Projected Carbon Emissions



Source: IPCC 2013b.

Between 2081 and 2100, the IPCC projects an average increase in surface temperature, with a *likely* range between 0.3°C (0.5°F) and 4.8°C (8.6°F), compared with 1986 through 2005, where the lower value corresponds to substantial future mitigation of carbon emissions (IPCC 2013b). At the national, regional, and local levels, there can be substantial differences in warming compared with the global average. This is due to the influence of smaller scale factors, such as topography and changes in land use, on local-scale climates (GCRP 2014). Elevated global average temperatures could persist even if atmospheric CO_2 concentrations decline. Because of the large heat capacity of the oceans, it may be centuries from now before all the warming from a given level of CO_2 concentrations are realized. Therefore, although reductions in or stabilization of CO_2 concentrations will slow the rate of temperature rise, temperatures will not drop from these reductions until the ocean has reached equilibrium with the atmosphere (Matthews and Caldeira 2008, IPCC 2013b). In addition, the IPCC projects that this temperature increase will affect sea level, causing a *likely* rise of 0.26 meter (0.85 feet) to 0.82 meter (2.7 feet) (IPCC 2013b). Satellite observations suggest such changes are beginning. In addition to IPCC projections, which do not include potential sea-level rise that could occur from melting/calving of major ice sheets, other studies, including semi-empirical analysis, indicate that sea-level rise could be even greater (*see* Figure 5.1.5-2). There is "*very high confidence* (more than 9 in 10 chance) that global mean sea level will rise at least 0.2 meter (7.9 inches) and no more than 2.0 meters (6.6 feet) by 2100" (NOAA 2012). Delaying reductions in anthropogenic GHG emissions will increase the concentration at which CO_2 stabilizes in Earth's atmosphere, increasing the risk of greater warming and greater sea-level rise (IPCC 2014a).

Figure 5.1.5-2. End-of-Century (~2090–2100) Estimates of Maximum and Minimum Global Mean Sea-Level Rise



Source: USACE 2014.

In addition to increases in global average temperature and sea level, climate change is expected to have many environmental, human health, and economic consequences. For a more in-depth analysis of the future impacts of climate change on various sectors, *see* Section 5.5 of this EIS.

5.1.6 Black Carbon and Other Aerosols

Aerosols are solid or liquid particles suspended in Earth's atmosphere. The chemical composition of aerosols varies enormously and can include sulfates, nitrates, dust, black carbon, and other chemical species (IPCC 2013b, CCSP 2009). Aerosols are either emitted directly from a source (e.g., power plants, forest fires, and volcanoes) into Earth's atmosphere or chemically created in the atmosphere from gases (IPCC 2013b, CCSP 2009). HD vehicles contribute to U.S. emissions of black carbon, but there is no evidence to suggest that the alternatives differ substantially in terms of their effect on black carbon and aerosol emissions. However, given their important influence on climate, this section provides an overview of these emissions and their climatic interactions.

Depending on meteorological conditions and other factors, aerosols typically remain in Earth's atmosphere from a few days to more than a week (IPCC 2013b). Their relatively short lifetimes can create regional areas of high aerosol concentrations nearby as well as some distance downwind from emissions source(s) (IPCC 2013b). Therefore, unlike GHGs, any climatic impact of aerosols could be evaluated at the regional scale.

An aerosol's effect on climate depends on its composition. Some aerosols, such as sulfates, reflect incoming sunlight back to space, causing a cooling effect; other aerosols, such as black carbon, absorb incoming sunlight, causing a warming effect (CCSP 2009, IPCC 2013b). In addition, some aerosols attract moisture/water vapor and can affect the lifetime and reflectivity of clouds. Overall, IPCC (2013b) believes that aerosols cool Earth's atmosphere from the reflection of incoming sunlight and their interaction with clouds, though large uncertainties exist (*see* Section 5.1.6.3). The overall effect of aerosols on precipitation is not known at the global scale, and this topic continues to be an active area of research (IPCC 2013b).

Among the aerosols, black carbon has recently attracted much attention because of its strong effect on Earth's energy balance. Black carbon is an aerosol that forms during incomplete combustion of certain fossil fuels (primarily coal and diesel) and biomass (primarily fuel wood and crop waste).[4] Reports from the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) suggest that a reduction in black carbon emissions could reduce global mean warming rates over the next few decades, while reductions in CO_2 emissions are required for reducing global mean warming over the long term (UNEP and WMO 2011).

There is no single accepted methodology for summarizing in a simple way the range of effects that black carbon emissions have on the climate or representing these effects and impacts in terms of CO_2e; significant scientific uncertainties remain regarding black carbon's total climate effect.[5] The interaction of black carbon (and other co-emitted aerosols) with clouds is especially poorly quantified (IPCC 2013b), and this factor is key to any attempt to estimate the net climate impacts of black carbon. Although black carbon is likely to be an important contributor to climate change, it is not feasible to quantify black carbon climate impacts in an analysis of the Proposed Action. Therefore, a qualitative description of the climatic effects and general characteristics of black carbon follows in Sections 5.1.6.1 through 5.1.6.5.

[4] Black carbon is often referred to as *soot* or *particulate matter*, when in fact it is only one *component* of soot and one *type* of particulate matter. It is sometimes referred to as "elemental carbon," although it is actually a slightly impure form of elemental carbon. As noted by Andreae and Gelencsér (2006), black carbon is often used interchangeably with other similar terms with slightly different definitions. Furthermore, definitions across literature sources are inconsistent.

[5] The range of uncertainty in the current magnitude of black carbon's climate-forcing effect is evidenced by the wide ranges presented in the IPCC Fifth Assessment Report (2013).

5.1.6.1 Emissions

Globally, developing countries are the primary emitters of black carbon because they depend more heavily on biomass-based fuel sources for cooking and heating and diesel vehicles for transport. They also have less stringent air emissions control standards and technologies. The United States contributes approximately 7 to 8 percent of the world's black carbon emissions (EPA 2012c), making the United States the eighth largest emitter worldwide (Lamarque et al. 2010).[6] In 2005, the United States emitted approximately 0.64 million ton of black carbon (EPA 2012c). The transportation sector is the single largest contributor in the United States, accounting for approximately 52 percent of U.S. black carbon emissions, followed by wildfires and agriculture/prescribed burns (Battye et al. 2002, Bond et al. 2004, EPA 2012c).[7] Approximately 80 percent of mobile-source black carbon emissions in the United States are from on-road and non-road diesel sources, at 208,473 and 145,289 short tons, respectively, for 2005 (EPA 2012c). There is considerable uncertainty surrounding black carbon emissions estimates; Ramanathan and Carmichael (2008) estimate 50 percent uncertainty in global estimates, while the uncertainty in regional emissions estimates can range from a factor of 2 to 5.

The *IPCC WG3 AR5* (2014b) suggests there is strong evidence to support the reduction of black carbon emissions from HD vehicles as a means for providing a short-term mitigation strategy to curb future global warming. If overall fuel consumption continues to increase over time, this could lead to an increase in black carbon emissions. However, improvements in emissions technology and reductions in black carbon emissions could offset some of the future increase in fuel consumption (IPCC 2014).

5.1.6.2 Climatic Interactions

Although black carbon has been an air pollutant of concern for years because of its direct human health effects, climate change experts have become concerned with it because of its influence on climate change (EPA 2009, 2012c). Recent studies suggest black carbon is a major contributor to anthropogenic warming because it affects regional net radiative forcing[8] in several ways: (1) it absorbs incoming or reflected solar radiation, warming the atmosphere around it; (2) it deposits on snow or ice, reducing the albedo[9] and enhancing melting; (3) as it warms the atmosphere, it triggers cloud evaporation; and (4) as it ages in the atmosphere, it can become hygroscopic, reducing precipitation and increasing the lifetime of clouds (IPCC 2013b, EPA 2009, Ramanathan and Carmichael 2008, Kopp and Mauzerall 2010, EPA 2012c). The following paragraphs discuss these interactions.

---

[6] This is consistent with the findings provided in the IPCC Fifth Assessment Report (2013), which suggest that North America emits between 0.3 to 0.4 Teragrams per 2000 year of black carbon, which equates to approximately 6 to 8 percent of the total emissions worldwide.

[7] Bond et al. (2004) used 1996 fuel data and estimated global black carbon emissions (in PM2.5) to be 8,000 gigagrams. This sector alone is responsible for 36 percent of all black carbon emissions in the United States, similar to that for prescribed forest burning. Battye et al. (2002) calculated total U.S. black carbon emissions at 433 gigagrams; the EPA 2001 National Emissions Inventory (NEI) database provides fine particle (PM2.5) emissions, which were then proportioned to black carbon for U.S. on-road diesel vehicles (65 to 89 gigagrams), non-road diesel vehicles (65 gigagrams), and on-road gasoline vehicles (16 to 35 gigagrams).

[8] Radiative forcing (RF) describes the magnitude of change in energy fluxes caused by a specific driver that can alter the Earth's energy budget. The IPCC (2013a) provides radiative forcing for 2011 relative to 1750. A positive RF leads to a warming while a negative RF leads to a cooling (IPCC 2013a).

[9] Surfaces on Earth (including land, oceans, and clouds, etc.) reflect solar radiation back to space. This reflective characteristic, known as albedo, indicates the proportion of incoming solar radiation the surface reflects. High albedo has a cooling effect because the surface reflects rather than absorbs most solar radiation.

Black carbon absorbs solar radiation and re-emits this energy into the surrounding air, thereby warming it. When black carbon particles are suspended in the air above a dark surface, solar radiation that would have reached the surface is reduced and instead warms the atmosphere. This causes a surface cooling effect referred to as surface "dimming" (Ramanathan and Carmichael 2008). When black carbon particles are suspended in the air above a light and reflective surface (such as snow or ice), which would normally reflect sunlight at a high rate, the particles have a lesser effect at Earth's surface. Regardless of the characteristics of the underlying surface, black carbon particles cause warming in the atmosphere above Earth's surface.

When black carbon is deposited on snow and ice, it reduces the albedo because it absorbs incoming solar radiation and contributes to enhanced melting (EPA 2009, Ramanathan and Carmichael 2008, Flanner et al. 2007, EPA 2012c). For example, in places where black carbon emissions are high (e.g., upwind of the Himalayan glaciers and the snow-laden Tibetan plateau), earlier snowmelt has been observed and attributed to black carbon deposition (Zemp and Haeberli 2007, Meehl et al. 2008). The Arctic has also experienced accelerated spring melting and a longer melt season in response to black carbon deposition (Quinn et al. 2008). In fact, research indicates that black carbon has contributed approximately 0.5 to 1.4°C (0.9 to 2.52°F) to Arctic warming since 1890 (Shindell and Faluvegi 2009). Another recent study modeled black carbon and dust deposition and found that they cause substantial warming over large areas of the Arctic Ocean and sub-Arctic seas during the fall and winter months (Goldenson et al. 2012). Impacts of black carbon on the Arctic vary with the origin of emissions. Emissions from within the Arctic (e.g., emissions from parts of Alaska, Canada, Greenland, Russia, and Norway) are more likely to stay close to Earth's surface and deposit on snow and ice, while emissions transported from the mid-latitudes are more likely to remain at high altitudes. It is suggested that emissions from within the Arctic affect surface temperatures five times more than emissions from mid-latitudes (Sand et al. 2013).

The complex interaction of black carbon with the radiative properties of clouds is an area under active research. Some aerosols suppress the formation of larger cloud droplets, which can extend the life of the cloud and increase cloud cover (IPCC 2013b, Ramanathan and Carmichael 2008). In addition, reducing precipitation can extend the atmospheric lives of aerosols. Although initially hydrophobic (i.e., the aerosol does not attract moisture/water vapor), black carbon becomes hygroscopic (i.e., the aerosol attracts moisture/water vapor) as it ages in the atmosphere, thus acting as a cloud condensation nucleus. This increases the number of droplets in clouds, thereby increasing the cloud albedo (Kopp and Mauzerall 2010). Conversely, black carbon radiatively warms the surrounding air as it absorbs solar radiation, which leads to evaporation of cloud droplets by lowering the relative humidity and reducing cloud cover (Ramanathan and Carmichael 2008). An important issue, which can vary by region, is which aerosols—non-black carbon or black carbon—dominate in cloud effects (Ramanathan and Carmichael 2008). The observed weakening of the summertime Indian monsoon has been attributed, in part, to black carbon atmospheric absorption (Ramanathan and Carmichael 2008, Meehl et al. 2008).

5.1.6.3 Net Radiative Effect

The *IPCC WG1 AR5* (2014b) suggests that the interaction of aerosols, including black carbon, with radiation and clouds leads to a cooling of -0.9 Watts per square meter (W/m^2), with *medium confidence* that the forcing is between -1.9 to -0.1 W/m^2 and a *likely* range of -1.5 to -0.4W/m^2.[10] From 1750 to 2010, the radiative forcing of black carbon emissions from fossil fuel and biofuel is estimated to have been a warming of 0.4 W/m^2, with a 5 to 95 percent uncertainty range of 0.05 to 0.8 W/m^2 (IPCC

[10] These estimates are based on global climate model results, satellite estimates, and expert judgment.

2013b).[11] These estimates do not account for the effect on other aspects that affect the radiative budget, such as interactions with cloud properties and changes in snow and sea ice. Of these additional effects, the radiative forcing associated with the deposition of black carbon on snow and sea ice is estimated to be 0.04 $W/m^{2,}$ with an uncertainty range of 0.02 to 0.09 W/m^2 (IPCC 2013b).

The ranges presented are, in part, due to the different treatment of black carbon across global-scale modeling studies and the variation in regional concentrations, which hinders attempts to obtain a consistent estimate of its radiative effects. For example, modeling studies vary in how several key factors are weighted, including emissions source strength and categories, changes in particle properties as it "ages" in the atmosphere, and the vertical distribution of black carbon (Ramanathan and Carmichael 2008, Jacobson 2010, Kopp and Mauzerall 2010). In addition, Spracklen et al. (2011) suggests black carbon acting to promote the development of cloud droplets plays a substantial role in increasing the radiative cooling caused by clouds, emphasizing the importance of including this mechanism when considering the particle's net effect on climate.

5.1.6.4 Comparison to Properties of Greenhouse Gases

Black carbon has a much shorter atmospheric lifespan than GHGs. The *IPCC WG1 AR5* (2014b) estimates the life of black carbon in the atmosphere as being approximately 7 to 10 days, generally depending on meteorological conditions. This is quite short compared with the atmospheric life of CO_2 in the atmosphere.[12] This short life suggests black carbon's effects are greatest near the emissions source; however, the nearby air molecules heated by black carbon's absorption of solar radiation can travel long distances, spreading this acquired warmth (Jacobson 2010). Given that the atmospheric loading of black carbon depends on being continually replenished, reductions in black carbon emissions can have an almost immediate (i.e., about a week) effect on radiative forcing.

As with the warming associated with GHGs, the physical environment reacts to the climatic impacts of black carbon. For example, black carbon can contribute to the warming of permafrost in the Arctic region. As permafrost warms, it releases large amounts of methane into the atmosphere, leading to additional warming (EPA 2009). As another example, the warming associated with black carbon can contribute to earlier melting of sea ice in the Arctic, exposing open oceans earlier in the year. The open oceans absorb solar radiation that would have been reflected by sea ice, leading to enhanced regional warming (EPA 2009). *See* Section 5.5.1.9 for a more discussion of these and other interactions.

5.1.6.5 Controls and Regulatory Options that Affect Black Carbon Emissions from Diesel Trucks

Based on estimates of U.S. on-road and non-road diesel emissions of black carbon in fine particles (PM2.5) (Battye et al. 2002) and global emissions of black carbon in PM2.5 (Bond et al. 2004), HD vehicles in the United States contribute slightly more than 3 percent of global black carbon emissions. The impact that the proposed HD fuel-efficiency standards could have on black carbon emissions is uncertain. Historically, diesel vehicles have emitted more black carbon than gasoline vehicles on a per-mile basis. Improved fuel efficiency associated with the Proposed Action will reduce black carbon emissions, as diesel fuel use will decrease compared to the No Action Alternative. Separately, widespread deployment of recent, more effective control technologies for particulate matter emissions

[11] IPCC (2014) used expert judgment and was informed by the findings of Bond et al. (2013) and Myhre et al. (2013).

[12] The removal of human-emitted CO_2 from the atmosphere by natural processes will take a few hundred thousand years (*high confidence*) (IPCC 2013b).

from diesel vehicles and the use of low-sulfur diesel fuel would most likely reduce emissions of black carbon.

5.2 Affected Environment

This section describes the affected environment in terms of current and anticipated trends in GHG emissions and climate. Effects of emissions and the corresponding processes that affect climate involve very complex processes with considerable variability, which complicates the measurement and detection of change. Recent advances in the state of science, however, are contributing to an increasing body of evidence that anthropogenic GHG emissions are impacting climate in detectable and quantifiable ways.

This section begins with a discussion of GHG emissions (*see* Section 5.2.1) and then climate (*see* Section 5.2.2). Because GHG emissions and climate impacts occur at not only the national scale (i.e., the scale of the alternatives under consideration) but also at the global scale, both discussions include descriptions of conditions globally and in the United States. Many themes in the discussions regarding conditions in the United States reappear in the global discussions.

5.2.1 Greenhouse Gas Emissions—Historic and Current

5.2.1.1 Global Emissions

Although humans have always contributed some level of GHG emissions to the atmosphere through activities like farming and land clearing, substantial anthropogenic contributions did not begin until the mid-1700s with the onset of the Industrial Revolution. People began burning coal, oil, and natural gas to light their homes, to power trains and cars, and to run factories and industrial operations. Today, fossil fuels are still the primary source of energy and predominant source of GHG emissions for the world.

As noted earlier, the concentration of atmospheric CO_2 has been rising rapidly. The atmospheric CO_2 level was estimated to be 278 ppm in 1750 and has since been rising steadily (IPCC 2014b citing Etheridge et al. 1996, Etheridge et al. 2002, NRC 2010b, and IPCC 2013a). Since the Industrial Revolution, atmospheric CO_2 concentration has risen to approximately 397 ppm in 2014 (NOAA 2015), about a 43 percent increase. In addition, the concentrations of CH_4 and N_2O in the atmosphere increased about 150 and 20 percent, respectively, by 2011 (IPCC 2013a).

In 2011, global GHG emissions were estimated to be 47,027 million metric tons of CO_2e ($MMTCO_2e$), a 37.9 percent increase since 1990 (WRI 2015).[13] In general, global GHG emissions have increased regularly, although annual increases vary according to a variety of factors (e.g., weather, energy prices, and economics).

The primary GHGs emitted are CO_2, CH_4, N_2O, and the fluorinated gases hydrofluorocarbons (HFCs), perfluorocompounds (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). In 2011, CO_2 emissions[14] comprised 74 percent of global GHG emissions on a global warming potential (GWP)-weighted basis, followed by CH_4 (17 percent) and N_2O (8 percent). Collectively, fluorinated gases represented 1.6 percent of global emissions covered by national inventories (WRI 2015).

[13] Unless otherwise stated, all GHG estimates cited in Section 5.2.1.1 include contributions from land-use change and forestry and international bunker fuels. The most recent emissions estimates for all gases from WRI CAIT are for 2011.

[14] These global GHG estimates *do not* include contributions from land-use change and forestry or international bunker fuels.

GHGs are emitted from a wide variety of sectors, including energy, industrial processes, waste, agriculture, and forestry. The energy sector is the largest contributor of global GHG emissions, accounting for 71 percent of global emissions in 2011. The next-highest contributors of GHG emissions are agriculture (13 percent) and industrial processes (6 percent) (WRI 2015). Transportation CO_2 emissions comprise roughly 13 percent of total global GHG emissions (included in the 71 percent cited above for the energy sector [WRI 2015]). Emissions from transportation are primarily due to the combustion of petroleum-based fuels to power vehicles. Global transportation CO_2 emissions have increased by 49 percent from 1990 to 2011 (WRI 2015).

5.2.1.2 U.S. Emissions

GHG emissions for the United States in 2013[15] were estimated at 6,673.0 $MMTCO_2e$ (EPA 2015). U.S. emissions comprise approximately 15 percent of global GHGs emitted (WRI 2015).[16] Annual U.S. emissions, which have increased 5 percent since 1990, are heavily influenced by "general economic conditions, energy prices, weather, and the availability of non-fossil alternatives" (EPA 2015).

Similar to the global trend, CO_2 is by far the primary GHG emitted in the United States, representing 82.5 percent of U.S. GHG emissions in 2013 (EPA 2015). Methane accounts for 9.5 percent of total GHGs on a GWP-weighted basis, followed by N_2O (5.3 percent) and the fluorinated GHGs or gases (2.6 percent) (EPA 2015).[17]

Most U.S. emissions are from the energy sector, largely due to CO_2 emissions from the combustion of fossil fuels, which alone account for 77 percent of total U.S. emissions (EPA 2015). The CO_2 emissions due to combustion of fossil fuels are from fuels consumed in the electric power (40 percent of fossil fuel emissions), transportation (33 percent), industry (16 percent), residential (6 percent), and commercial (4 percent) sectors, with the remaining emissions, from U.S. territories, accounting for 1 percent of the total (EPA 2015). When U.S. CO_2 emissions are apportioned by end use, transportation is the single leading source of U.S. emissions from fossil fuels, causing almost one-third of total CO_2 emissions from fossil fuels (EPA 2015).[18]

CO_2 emissions from HD vehicles account for almost a quarter of U.S. transportation CO_2 emissions, and have increased by 72 percent since 1990 (EPA 2015). This increase was primarily driven by the cost competitiveness and use of a manufacturing industry inventory system called Just in Time (JIT), which is a manufacturing production system that reduces inventory and associated carrying costs. Low fuel prices during the 1900s and much of the 2000s made trucks a more attractive mode of transportation, and, in conjunction with the rise in businesses using the JIT inventory management to transport goods in a way that is more quick and timely, these trends contributed to the increased market share for trucks (C2ES 2014a). From 1970 to 2003, energy consumption increased more rapidly in the HD vehicle sector than in the light-duty vehicle sector (C2ES 2014d).

[15] Most recent year for which an official EPA estimate is available (EPA 2015).

[16] Based on global and U.S. estimates for 2011, the most recent year for which a global estimate is available. Excluding emissions and sinks from land use change and forestry and international bunker fuels.

[17] Fluorinated GHGs or gases include PFCs, HFCs, SF_6, and NF_3.

[18] Apportioning by end use allocates emissions associated with electricity generation to the sectors (residential, commercial, industrial, and transportation) where it is used.

5.2.2 Climate Change Effects—Historic and Current

In its most recent assessment of climate change (the Fifth Assessment Report [AR5]), the Intergovernmental Panel on Climate Change (IPCC) states that, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC 2013a). The IPCC concludes that, at continental and global scales, numerous long-term changes in climate have been observed. These include changes in polar (Arctic and Antarctic) temperatures and ice cover, widespread changes in precipitation amounts, ocean salinity, and extreme weather including droughts, heat waves, and precipitation intensity (IPCC 2013b).

This section provides an overview of observed historical and current climate change and ocean salinity effects and impacts at the global, regional, and national scales. Much of the material that follows is drawn from the following studies, including the citations therein: AR5 Working Group II (Impacts, Adaptation, and Vulnerability) Summary for Policymakers (IPCC 2013a), Third National Climate Assessment (GCRP 2014), and Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act (EPA 2009). The impacts associated with these observed trends are further discussed in Section 5.5.

Sections 5.2.2.1 through 5.2.2.3 address increased temperatures, sea-level rise, and changes in precipitation patterns, respectively. Section 5.4 of this EIS provides a quantitative analysis of the effects of the regulatory alternatives on each of these three climate attributes.

Sections 5.2.2.4 through 5.2.2.6 address increased incidence of severe weather, changes in ice cover and extent, and ocean acidification. They are described to provide a more complete discussion of historic and current climate change trends and impacts. As discussed below, although the incremental effects of the alternatives are not quantified for these impacts, the more the alternatives reduce GHG emissions, the more they reduce the direct and indirect risks associated with these phenomena.

5.2.2.1 Increased Temperatures

5.2.2.1.1 Radiative Forcing (RF)

Global average surface temperature has been increasing over the past century in response to anthropogenic GHG emissions. The IPCC states that scientific evidence shows that the total anthropogenic RF has increased by 2.29 watts per square meter (Wm^{-2}) (plus 1.04 or minus 1.16 Wm^{-2}) and is responsible for the observed warming. The RF from increased atmospheric CO_2 concentration alone is estimated to be 1.68 Wm^{-2} (plus 0.35 or minus 0.35 Wm^{-2}) (IPCC 2013a). The IPCC also indicates that previous estimates of total anthropogenic RF had, in fact, underestimated recent changes in RF: "The total anthropogenic RF best estimate for 2011 is 43 percent higher than that reported in AR4 for the year 2005" (IPCC 2013a).

5.2.2.1.2 Average Temperatures

In the years from 1880 to 2012, the global mean surface temperature has risen by 0.85 plus or minus about 0.20°C (1.53 plus or minus about 0.36°F) (IPCC 2013a). Temperatures are rising at an increasing rate. The average rate of increase since 1951 was 0.12 plus or minus 0.03°C (0.22 plus or minus 0.05°F) per decade. The average Arctic temperature has increased at almost twice the global average rate over at least the past several decades (GCRP 2014). Air temperatures over land are warming more rapidly than those over oceans (GCRP 2014, IPCC 2013a).

Throughout the 2000s, the contiguous United States and Alaska experienced a lack of cold waves, compared with historical averages (GCRP 2014). Similar to the global trend, the U.S. average temperature is now 1.30–1.90°F warmer than it was in 1895, and this rate of warming is increasing—most of the warming has occurred since 1970 (GCRP 2014). Global ocean temperatures have also continued to warm. The upper 75 meters (246 feet) of the global ocean has warmed by 0.11 plus or minus 0.02°C (0.20 plus or minus 0.4°F) per decade between 1971 and 2010 (IPCC 2013a). Surface temperatures are not rising uniformly around the globe. For example, some areas of the southeastern, Midwestern, and Great Plains regions of the United States have experienced "warming holes" because recent temperature observations during the 20th century suggest only minor to no warming trends in those areas (GCRP 2014).

5.2.2.1.3 Extreme Temperatures

Across regions of the world including the United States, extreme temperatures have changed substantially since about 1950. Hot days, hot nights, and heat waves have become more frequent; cold days, cold nights, and frost have become less frequent (EPA 2009, GCRP 2014, IPCC 2013b). Since 1950, the frequency of heat waves experienced in the United States has increased, although in many regions the heat waves recorded in the 1930s remain the most severe on record; one notable exception is that the drought that has been occurring in the western states for the last decade is the most severe on record (GCRP 2014). Additionally, fewer unusually cold days occurred in the past few decades, with fewer severe cold waves than historically indicated. The number of extreme cold events in the 2000s–2010s, thus far, has been at the lowest level dating back to at least 1895 (the inception of detailed record-keeping) (GCRP 2014). It is now considered *very likely* that humans have contributed to extreme heat events since the middle of the 20th century and is also *likely* that human activities have doubled the probability of extreme heat events in some regions (IPCC 2013b).

Weather balloons (which have been used since around the turn of the 20th century and were in routine use by 1958) and satellites (which have been used since the 1970s) have recorded increases in temperatures since their inception (GCRP 2014). In addition, higher temperatures are also independently confirmed by other global observations. For example, scientists have documented shifts to higher latitudes and elevations of certain flora and fauna habitat. In high and mid-northern latitudes, the growing season increased an average of approximately 2 weeks during the second half of the 20th century (IPCC 2014a, GCRP 2014), and plant flowering and animal spring migrations are occurring earlier (EPA 2009, IPCC 2014a, GCRP 2014). Permafrost top layer temperatures have generally increased since the 1980s (approximately 3°C [5°F] in parts of Alaska and 2°C [4°F] in northern Russia), while the depths of seasonally frozen ground has, in some parts of the Eurasian continent, decreased since 1930 by approximately 0.3 meter (1 foot) (IPCC 2013b). The 4 to 5°F warming in Alaska permafrost has been recorded at a depth of 65 feet (GCRP 2014 citing NRC 2011 and Hawkings and Sutton 2009); at a depth of about 3 feet, the warming has been recorded as 6 to 8°F (GCRP 2014 citing Hansen and Sato 2012).

5.2.2.2 Sea-Level Rise

5.2.2.2.1 Contributions to Sea-Level Rise

Higher temperatures cause sea level to rise due to both thermal expansion of water and an increased volume of ocean water from melting glaciers and ice sheets. Since the early 1970s, glacier loss and thermal expansion, together, contributed approximately 75 percent to observed sea-level rise. It is *very likely* that human contributions to sea-level rise are substantial (IPCC 2013b).

Between 1971 and 2010, global ocean temperature warmed by approximately 0.25°C (0.45°F) in the top 200 meters (0.12 mile) (IPCC 2013b). In the top 700 meters (0.43 mile) of the ocean column, warming

contributed an average of 0.6 plus or minus 0.2 millimeter (0.024 plus or minus 0.0079 inch) per year to sea-level rise (IPCC 2013b), because seawater expands as it warms. Mountain glaciers, ice caps, and snow cover have declined on average, contributing further to sea-level rise. Losses from the Greenland and Antarctic ice sheets *very likely* contributed to sea-level rise from 1993 to 2010, and satellite observations indicate that they have contributed to sea-level rise in the years since (IPCC 2013b). Dynamical ice loss (i.e., where a supporting ice shelf situated along the boundary between the glacier and ocean collapses, thereby allowing for the downgradient flow of ice streams within the glacier to reach the ocean) explains most (up to 74 percent) of the Antarctic net mass loss and about half of the Greenland net mass loss (IPCC 2013b).

5.2.2.2.2 Observed Global Sea-Level Rise

It is *very likely* that global average sea level rose at an average rate of 1.7 plus or minus 0.3 millimeters (0.07 plus or minus 0.011 inch) per year from 1901 to 2010, with the rate increasing to approximately 3.2 plus or minus 0.4 millimeters (0.13 plus or minus 0.016 inch) per year from 1993 to 2010 (IPCC 2013a). Global mean sea level rose about 19 centimeters (7.5 inches) from 1901 to 2010 (IPCC 2013a).

5.2.2.2.3 Observed Regional Sea-Level Rise

Sea-level rise is not uniform across the globe, primarily due to changes in the elevation of the land surface. The largest increases since 1992 have been in the western Pacific and eastern Indian Oceans; meanwhile, sea level in the eastern Pacific and western Indian Oceans has actually been falling (IPCC 2013b citing Beckley et al. 2010).

Nationally, relative sea level is rising 0.8 to 1.2 inches per decade along most of the Atlantic and Gulf coasts, and a few inches per decade along the Louisiana coast (the faster pace being due to relatively rapid land subsidence). Sea level is falling (due to land uplift) at the rate of a few inches per decade in parts of Alaska (EPA 2009, National Science and Technology Council 2008).

Sea-level rise extends the zone of impact of storm surges and waves from tropical and other storms farther inland, causing coastal erosion and other damage. Resulting shoreline erosion is well documented. Since the 1970s, half of the coastal area in Mississippi and Texas has been eroding horizontally by an average of 2.6 to 3.1 meters (8.5 to 10.2 feet) per year. In Louisiana, a full 90 percent of the shoreline has been eroding at an average horizontal rate of more than 12.0 meters (39 feet) per year (EPA 2009 citing Nicholls et al. 2007).[19]

5.2.2.3 Changes in Precipitation Patterns

As the climate warms, evaporation from land and oceans will increase and more moisture can be held in the atmosphere (GCRP 2014). Depending on atmospheric conditions, this translates to some areas experiencing increases in precipitation events, while other areas are left more susceptible to droughts. Average atmospheric water vapor content has increased since at least the 1970s over land and the oceans, and in the upper troposphere, largely consistent with air temperature increases (IPCC 2013b). As a result of changes in climate including increased moisture content in the atmosphere, heavy precipitation events have increased in frequency over most land areas (IPCC 2013a).

[19] The shoreline erosion in Louisiana is also affected by human alterations and loss of sediment supply (EPA 2009e).

5.2.2.3.1 Global, Regional, and National Precipitation Trends

Long-term trends in global precipitation amounts have been observed since 1901. Between 1901 and 2010, increases in precipitation have been observed in the mid- and higher-latitudes of both the northern and southern hemispheres, specifically in northwestern and eastern parts of North America, parts of Europe and Russia, and southern South America. Drying has been observed in the Sahel region of Africa, the Mediterranean, southern Australia, and parts of southeastern Asia. Spatial and temporal variability for precipitation is high, and data are limited for some regions (IPCC 2013b).

Over the contiguous United States, total annual precipitation increased approximately 5 percent from 1901 to 2014, on average. The greatest increases since 1991 (relative to 1901 to 1960) were noted in the Midwest (9 percent), the Northeast (8 percent), and the southern Great Plains (8 percent), and there were notable decreases in Hawaii and areas of the Southwest (GCRP 2014). Heavy precipitation events also increased, primarily during the last 3 to 5 decades, equating to more than 30 percent above the 1901 to 1960 average. This has been observed mainly in the Northeast (71 percent) and Midwest (37 percent) regions (GCRP 2014).

5.2.2.3.2 Global, Regional, and National Trends in Droughts

Observations of increased dryness since the 1950s suggest that some regions of the world have experienced longer, more intense droughts caused by higher temperatures and decreased precipitation, particularly in the tropics and subtropics (IPCC 2013b). Spatial variability for dryness is high and data availability is limited in some regions to draw global conclusions. While there is *likely* increased dryness or drought in East Asia, the Mediterranean, and West Africa, there has *likely* been decreased dryness observed in central North America and northwest Australia (IPCC 2013b).

Trends in droughts have been changing for some regions of the United States over the past 50 years (GCRP 2014). Most regions in the United States experienced decreases in drought severity and duration over the 20th century due to increasing average precipitation and the frequency of heavy precipitation events; although there are exceptions to this trend, such as the severe drought in the Southwest from 1999 to 2008 (EPA 2009), recent severe droughts in Texas in 2011 (GCRP 2014), the Midwest in 2012 (GCRP 2014) and California in 2014 continuing into 2015 (USGS 2015). According to tree ring data, drought conditions in the western United States over the last decade may represent the driest conditions in 800 years (GCRP 2014).

5.2.2.3.3 Global, Regional, and National Streamflow Trends

Melting snow and ice, increased evaporation, and changes in precipitation patterns all affect surface water. Previous assessments have indicated variable changes in streamflow and river discharge, with most increases observed at higher latitudes. Mean annual streamflow decreased approximately 2 percent per decade over the past century in the central Rocky Mountain region (IPCC 2007 citing Rood et al. 2005), while high streamflow increased 25 percent in the past 60 years in the eastern United States (IPCC 2013b citing Groisman et al. 2004). More recent assessments show even greater global variability in trends, where decreases in streamflow were observed in mainly low and mid-latitude river basins, while increasing flow at higher latitudes may be resulting from possible permafrost thawing and increased snowmelt (IPCC 2013b). Changes in precipitation have also been identified as a major driver for changing discharge trends across regions (IPCC 2013b).

5.2.2.3.4 Global, Regional, and National Trends in Snow Cover

Across the northern hemisphere, annual mean snow cover extent has decreased 53 percent over the period 1967 to 2012 (IPCC 2013b). Recent analysis of Arctic snowpack indicates that changes in air temperature, decreased surface albedo, and increased atmospheric water vapor have driven trends in snow cover recession observed between 1972 and 2006 (GCRP 2014 citing Shi et al. 2013). Between 2008 and 2012, Eurasia set five records for minimum snow extent during late spring, and North America set records in 3 years in the same period (GCRP 2014 citing Derksen et al. 2012). In addition, North America, Europe, and southern and east Asia have experienced a decreasing number of snowfall events, *likely* due to increasing winter temperatures (IPCC 2013b).

5.2.2.4 Increased Incidence of Severe Weather Events

Analysis continues to support conclusions that heavy precipitation events have increased globally since 1951, with some regional and sub-regional variability (IPCC 2013b). Tropical cyclones appear to be increasing in intensity since 1970, but no clear trend in the frequency of tropical cyclones each year has been observed. Developing long-term trends of tropical cyclones continues to be problematic, because it has been difficult to draw *high confidence* conclusions with respect to observations prior to the satellite era (IPCC 2013b). However, there is observational evidence of an increase in intense tropical cyclone activity correlated with increases of tropical sea-surface temperatures in the North Atlantic, which includes the Atlantic Multidecadal Oscillation, since about 1970 (GCRP 2014). The frequency, intensity, and duration of hurricanes in the North Atlantic, including Category 4 and 5 hurricanes, have increased substantially since the early 1980s (GCRP 2014).

While recent assessments indicate that it is *unlikely* that the annual frequency of tropical storms and hurricanes have increased over the past century in the North Atlantic, the increase in intensity since 1970s in that region is *virtually certain* (IPCC 2013b). Additionally, recent models project that climate change may increase the frequency of the most intense hurricanes by the end of the century, but it is still unclear how overall frequency of events might change (GCRP 2014).

Evidence is insufficient to determine whether there are trends in large-scale phenomena such as the Meridional Overturning Circulation,[20] or in small-scale phenomena such as tornadoes, hail, lightning, and dust storms (IPCC 2013b).

5.2.2.5 Changes in Ice Cover and Permafrost

Changes in air and ocean temperatures, precipitation onto the ice mass, and water salinity are affecting glaciers, sea-ice cover, and ice sheets. Numerous studies have confirmed that glaciers and ice sheets have substantially shrunk in the past half century. Satellite images have documented the loss of mass from the Greenland ice sheet and the West Antarctic ice sheet (IPCC 2013b, GCRP 2014); since 1979, the annual average Arctic sea-ice area has been declining at a rate of 3.5 to 4.1 percent per decade (IPCC 2013b). Warming in the Arctic has proceeded at about twice the rate as elsewhere, leading to decreases in summer sea-ice extent, glacier and ice sheet mass loss, coastal erosion, and permafrost thawing (IPCC 2013b).[21] Some Arctic ice that previously was thick enough to last through summer has now thinned enough to melt completely in summer. In 2007, sea-ice extent was approximately 23 percent less than the previous all-time minimum observed in 2005 (EPA 2009, National Science and Technology Council

[20] A mechanism for heat transport in the North Atlantic Ocean, by which warm waters are carried north and cold waters are carried toward the equator.

[21] Permafrost thawing releases CO_2 and CH_4 into the atmosphere (*see* Section 5.5.1.9).

2008). Average winter sea-ice thickness in the Arctic Basin *likely* decreased by approximately 1.3 and 2.3 meters (4.27 to 7.55 feet) from 1980 to 2008 (IPCC 2013b). The multi-year ice extent (ice that lasts at least two summers) has declined from about 7.9 million square kilometers (3 million square miles) in 1980 to as low as 3.5 million kilometers (1.35 million square miles) in 2012 (IPCC 2013b). These area and thickness reductions allow winds to generate stronger waves, which have increased shoreline erosion along the Alaskan coast. Alaska has also experienced increased thawing of the permafrost base of up to 1.6 inches per year since 1992 (EPA 2009, National Science and Technology Council 2008).

5.2.2.6 Acidification of Oceans

Increasing atmospheric CO_2 concentration has forced oceans to absorb more CO_2 in recent decades, which lowers the pH of the water. When CO_2 dissolves in seawater, the hydrogen ion concentration of the water increases; this is measured as a decline in pH. Compared to the pre-industrial period, the pH of the world's oceans has dropped 0.1 unit (IPCC 2013b). Because pH is measured on a logarithmic scale, this represents a 30 percent increase in the hydrogen ion concentration of seawater, a substantial acidification of the oceans. As discussed more fully in Section 5.6, although research on the ultimate impacts of ocean acidification is limited, available observational, laboratory, and theoretical studies indicate that acidification may interfere with the calcification of coral reefs and, therefore, inhibit the growth and survival of coral reef ecosystems (EPA 2009, GCRP 2014, IPCC 2013b).

5.3 Analysis Methods

The methods NHTSA used to characterize the effects of the action alternatives on climate have three key elements:

- **Analyzing the effects of each alternative on GHG emissions.** Many analyses of policies and regulations express their goals, and measure their effectiveness, in terms of GHG emissions reductions.
- **Estimating the monetized damages associated with GHG emissions and reductions attributable to each alternative.** Economists have estimated the incremental effect of GHG emissions, and monetized those effects, to express the social cost of carbon (SCC), in terms of dollars per ton of CO_2. By multiplying CO_2 emissions reductions by the SCC, NHTSA derived a monetized estimate of the benefits of emissions reductions.
- **Analyzing how GHG emissions and reductions under each alternative affect the climate system (climate effects).** Climate models characterize the relationship between GHG emissions and various climatic parameters in the atmosphere and ocean system, including temperature, precipitation, and sea level. NHTSA translated the changes in GHG emissions associated with each action alternative to changes in temperature, precipitation, and sea level in relation to the No Action Alternative.[22]

[22] As explained in Chapter 2, the analysis of direct and indirect impacts compares action alternatives with the No Action Alternative, which reflects a small forecast increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, due to market-based incentives for improving fuel efficiency. By including these market-based improvements in the No Action Alternative, this analysis attempts to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the proposed rule, and not attributable to reasonably foreseeable future actions by manufacturers.

Also as explained in Chapter 2, the cumulative impacts analysis compares the same action alternatives with the No Action Alternative, which assumes no increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond (i.e., no increase beyond the 2014–2018 Phase 1 HD standards). In other words, this baseline does not take into account market-based incentives for improving fuel efficiency. By comparing the action alternatives to this baseline, the cumulative impacts analysis

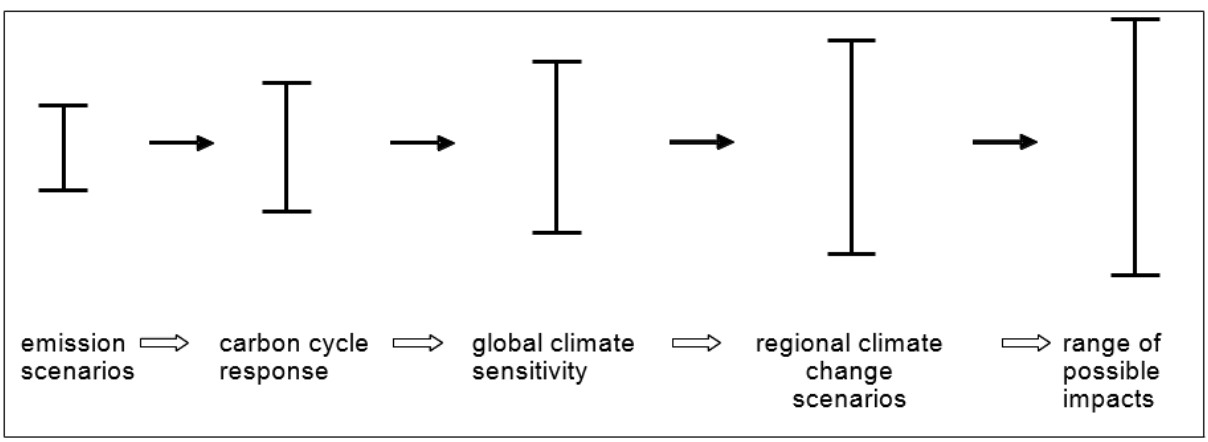
In this EIS, impacts on GHG emissions and the climate system are expressed in terms of emissions, CO_2 concentrations, temperature, precipitation, and sea level for each of the action alternatives.

Comparisons between the No Action Alternative and each action alternative are also presented to illustrate the differences in environmental effects among the alternatives. The impact of each action alternative on these results is measured by the difference in the climate parameter (CO_2 concentration, temperature, sea level, and precipitation) under the No Action Alternative and the climate parameter under that action alternative. For example, the reduction in CO_2 emissions attributable to an action alternative is measured by the difference in emissions under that alternative and emissions under the No Action Alternative. The methods used to characterize emissions and climate impacts involve considerable uncertainty. Sources of uncertainty include the following, in addition to many other factors:

- The pace and effects of technology changes in the transportation sector and other sectors that emit GHGs.
- Changes in the future fuel supply and fuel characteristics that could affect emissions.
- Sensitivity of climate to increased GHG concentrations.
- The rate of change in the climate system in response to changing GHG concentrations.
- Potential existence of thresholds in the climate system (which cannot be predicted or simulated).
- Regional differences in the magnitude and rate of climate change.

Moss and Schneider (2000) characterize the "cascade of uncertainty" in climate change simulations (Figure 5.3-1). As indicated in Figure 5.3-1, the emissions estimates used in this EIS have narrower bands of uncertainty than the global climate sensitivity, which is less uncertain than regional climate change impacts. The impacts on climate are, in turn, less uncertain than the impacts of climate change on affected resources (such as terrestrial and coastal ecosystems, human health, and other resources discussed in Section 5.5). Although the uncertainty bands broaden with each successive step in the analytic chain, all values within the bands are not equally likely; the mid-range values have the highest likelihood.

Figure 5.3-1. Cascade of Uncertainty in Climate Change Simulations



Source: Moss and Schneider 2000

reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 and the direct and indirect impacts of Phase 2 HD standards associated with each action alternative.

Scientific understanding of the climate system is incomplete; like any analysis of complex, long-term changes to support decisionmaking, evaluating reasonably foreseeable impacts on the human environment involves many assumptions and uncertainties. This EIS uses methods and data to analyze climate impacts that represent the best and most current information available on this topic, and that have been subjected to extensive peer review and scrutiny. The information cited throughout this section that is extracted from the most recent EPA, IPCC, and GCRP reports on climate change has endured a more thorough and systematic review process than information on virtually any other topic in environmental science and policy. The tools used to perform the climate change impacts analysis in this EIS, including the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) and the objECTS version of the Global Change Assessment Model (GCAM), are widely available and generally accepted in the scientific community.

The U.S. Climate Change Science Program Synthesis and Assessment Product 3.1 (SAP 3.1) on the strengths and limitations of climate models (CCSP 2008a) provides a thorough discussion of the methodological limitations regarding modeling. Additionally, Chapter 9, Evaluation of Climate Models of *IPCC WG1 AR5* provides an evaluation of the performance of global climate models. Readers interested in a detailed treatment of this topic will find the SAP 3.1 report and Chapter 9 of *IPCC WG1 AR5* useful in understanding the issues that underpin the modeling of environmental impacts of the Proposed Action and the range of alternatives on climate change.

5.3.1 Methods for Modeling Greenhouse Gas Emissions

The emissions estimates in this EIS include GHG emissions resulting from HD vehicle fuel combustion (tailpipe emissions), as well as upstream emissions from the production and distribution of fuel. GHG emissions were estimated by EPA using two models:

- The Motor Vehicle Emissions Simulator (MOVES) model, described in Section 2.3.2, was used to calculate tailpipe emissions. In addition, for 2b/3 vehicles, NHTSA used the Volpe Model to calculate tailpipe emissions.
- The Greenhouse Gases and Regulated Emissions in Transportation (GREET) model, developed by the U.S. Department of Energy (DOE) Argonne National Laboratory, was used to estimate emissions associated with production, transportation, and storage of gasoline and diesel from crude oil as well as emissions associated with the generation of electricity.

Emissions under each action alternative were compared against those under the No Action Alternative to determine the impact of the action alternative on emissions. GHG emissions from Phase 2 HD standards were estimated using the methods described in Section 2.3. For the climate analysis, GHG emissions trajectories are projected through year 2100. NHTSA estimated GHG emissions for the HD vehicle fleet for 2051 to 2100 by applying the projected rate of change in U.S. transportation fuel consumption over this period from GCAM. For 2051 through 2100, the GCAM Reference and GCAM 6.0 scenarios project that U.S. road transportation fuel consumption will decline slightly due primarily to (1) assumed improvements in efficiency of internal combustion engine-powered vehicles and, (2) increased deployment of non-internal combustion engine vehicles with higher drivetrain efficiencies. However, the projection of road transport fuel consumption beyond 2050 does not change substantially. Therefore, emissions remain relatively constant from 2050 through 2100. The assumptions and methods used to develop the GHG emissions estimates for this EIS are broadly consistent with those used in the *MY 2012–2016 CAFE Final EIS* (NHTSA 2010), *MY 2014–2018 Phase 1 HD Final EIS* (NHTSA 2011), and the *MY 2017–2025 CAFE Final EIS* (NHTSA 2012).

The emissions estimates include global CO_2, CH_4, and N_2O emissions resulting from direct fuel combustion and the production and distribution of fuel and electricity (upstream emissions). The MOVES model also estimated the following non-GHG emissions, which are used as inputs in MAGICC6: sulfur dioxide (SO_2), NO_x, CO, and volatile organic compounds (VOCs).

Fuel savings from more stringent HD vehicle fuel efficiency standards would result in lower emissions of CO_2, the main GHG emitted as a result of refining, distribution, and use of transportation fuels. There is a direct relationship among fuel efficiency, fuel consumption, and CO_2 emissions. Fuel efficiency describes how much fuel a vehicle requires to perform a certain amount of work (for example, how many miles it can travel or how many tons it can carry per mile traveled). A vehicle is more fuel-efficient if it can perform more work while consuming less fuel. Lower fuel consumption reduces CO_2 emissions directly because the primary source of vehicle-related CO_2 emissions is the combustion of carbon-based fuel in internal combustion engines; combustion of a hydrocarbon essentially produces energy (used to power the vehicle), CO_2, and water. Therefore, fuel consumption is directly related to CO_2 emissions, and CO_2 emissions are directly related to fuel efficiency.

For the analysis in this EIS, NHTSA estimated reductions in CO_2 emissions resulting from fuel savings by assuming that the carbon content of gasoline, diesel, and other fuels is converted entirely to CO_2 during the combustion process. Specifically, NHTSA estimated CO_2 emissions from fuel combustion as the product of the volume of each type of fuel consumed (in gallons), its mass density (in grams per gallon), the fraction of its total mass represented by carbon (measured as a proportion), and CO_2 emissions per gram of fuel carbon (the ratio of the molecular weights of CO_2 and elemental carbon). NHTSA used two models to estimate fuel consumption and emissions impacts for various vehicle categories: (1) EPA's MOVES model for tractor-trailers and vocational vehicles, and (2) DOT's Volpe model for HD pickups and vans.

Reduced fuel consumption also lowers CO_2 emissions that result from the use of carbon-based energy sources during fuel production and distribution. EPA estimated the global reductions in CO_2 emissions during each phase of fuel and electricity production and distribution (i.e., upstream emissions) for various vehicle categories using (1) a combination of EPA's GREET tool for upstream emissions impacts and the MOVES model emissions factors for tractor-trailers and vocational vehicles, and (2) DOT's Volpe model for HD pickups and vans. The upstream emissions were estimated using the CO_2 emissions rates obtained from the GREET 1 2013 model using the previous assumptions about how fuel savings are reflected in reductions in activity during each phase of fuel production and distribution The total reduction in CO_2 emissions from improving fuel efficiency under each alternative is the sum of the reductions in motor vehicle emissions from reduced fuel combustion plus the reduction in upstream emissions from a lower volume of fuel production and distribution. Emissions reductions continue well after the model years covered under the rule, as it is assumed that future new vehicles meet or exceed the efficiency required under the final year of the rule.

5.3.2 Social Cost of Carbon

This section describes the methods used to estimate the monetized damages associated with GHG emissions and the reductions in those damages that would be attributable to each action alternative. NHTSA adopted an approach that relies on estimates of the SCC that were developed by the Interagency Working Group on Social Cost of Carbon. This approach is consistent with the analysis of GHG impacts in the NHTSA and EPA joint Preliminary Regulatory Impact Analysis (Preliminary RIA) for the Phase 2 HD Fuel Efficiency Improvement Program.

The SCC is an estimate of the monetized damages associated with an incremental increase in annual CO_2 emissions. To estimate the monetized benefits associated with GHG reductions under each action alternative, NHTSA multiplied the estimated value of the SCC during each future year by the emissions reductions estimated to result during that year. NHTSA then discounted the sum of future benefits to provide the net present value in 2014. The following description parallels the discussion about GHG benefits in the NHTSA and EPA joint Preliminary RIA and provides details of this analysis.

The SCC estimates have been developed to include climate-related changes in agricultural productivity, human health, asset damages, and ecosystem services, among other factors. The estimates used in this analysis were updated in May 2013, and slightly revised in November 2013 (from the original 2010 estimates), through an interagency process that included DOT, EPA, and other Executive Branch entities. The 2013 update did not revisit the 2010 modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emissions scenarios or equilibrium climate sensitivity). Rather, improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves and used for analyses in peer-reviewed publications. The 2010 SCC Technical Support Document (2010 SCC TSD) provides a complete discussion of the methods used to develop these estimates and the 2013 SCC TSD presents and discusses the updated estimates. The updated estimates, based on updated models (DICE, PAGE, and FUND) are greater than the estimates published in 2010. This increase in damage costs is due to a number of factors such as explicit consideration of damages from sea level rise in the DICE and PAGE models. The TSD from 2010 indicated that damages in 2015 would be approximately $6 (in 2007 dollars) per metric ton of CO_2 ($MTCO_2$) emitted when calculated at the highest discount rate (5 percent) and using the average SCC; the 2013 analysis estimates the damages in 2015 to be $12 per $MTCO_2$ (in 2012 dollars) at the same discount rate and average SCC.

The interagency group selected four SCC values for use in regulatory analyses; NHTSA has converted these values to 2012 dollars for this analysis. Values for emissions occurring in 2015 are approximately $12, $40, $62, and $118 per $MTCO_2$ (in 2012 dollars). The first three values are based on the average SCC from three integrated assessment models, at discount rates of 5, 3, and 2.5 percent, respectively. SCCs at several discount rates are included because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because there is no consensus on the appropriate rate to use in an intergenerational context. The fourth value is the 95th percentile of the SCC from all three models at a 3 percent discount rate. This value is included to represent higher-than-expected impacts from temperature change farther out in the tails of the SCC probability distributions. Low-probability, high-impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models, and the use of a probability density function for equilibrium climate sensitivity in all three models. Treating climate sensitivity probabilistically allows the estimation of SCC at potential higher temperature outcomes, which have correspondingly higher projections of damages.

The SCC increases over time because incremental increases in emissions are expected to produce progressively larger incremental damages over future years as physical and economic systems become more stressed in response to greater climatic change. Note that the interagency group estimated the growth rate of the SCC directly using the three integrated assessment models rather than assuming a constant annual growth rate. This helps ensure that the estimates are internally consistent with other modeling assumptions. Table 5.3.2-1 lists the SCC estimates used in this analysis. Note that the interagency group only provided estimates of the SCC through 2050. Therefore, unlike other elements of the climate change analysis in the EIS, which generally extend to 2100, the SCC analysis covers a shorter period.

Although CO_2 is the GHG emitted by human activities into the atmosphere that has the greatest global climate effect due to its abundance, other GHGs—including CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3—also contribute to climate change. However, because these gases differ in atmospheric lifetimes, their relative damages are not constant over time. To incorporate the social costs of emissions of non-CO_2 gases, NHTSA performed a sensitivity analysis by converting CH_4 and N_2O emissions into $MTCO_2$ equivalent ($MTCO_2e$),[23] then multiplying the carbon equivalents by the SCC. Although this method is not set forth in the TSD (because the document's approach is intended only for CO_2 emissions), it has been used by others and is less uncertain than assuming the social costs of non-CO_2 GHGs are zero (Marten and Newbold 2011). The social costs of non-CO_2 gases are considered in a separate sensitivity analysis.

Table 5.3.2-1 lists global SCC estimates, in constant 2012 dollars per metric ton of GHGs (in CO_2e) emitted. The first three columns of SCC estimates are the average SCCs across all three of the integrated assessment models used in the interagency group SCC analysis. The final column indicates the 95th percentile of the SCC at a 3 percent discount rate across the three models. These values are used in the subsequent calculations in this section.

Table 5.3.2-1. Social Cost of Carbon, 2010–2050 (2012 dollars per $MTCO_2e$)

Year	Discount Rate and Statistic[a]			
	5% Discount Rate, Average Value ($)	3% Discount Rate, Average Value ($)	2.5% Discount Rate, Average Value ($)	95th Percentile Value at 3% Discount Rate ($)
2010	12	35	55	96
2012	12	37	58	105
2014	12	39	61	113
2015	12	40	62	118
2020	13	46	69	138
2025	15	51	75	155
2030	17	56	81	172
2035	21	61	86	189
2040	23	66	93	206
2045	26	71	99	223
2050	28	77	105	238

Notes:
[a] The dollar amounts in these columns are rounded for presentation purposes.

Many serious challenges arise when attempting to assess the incremental economic impacts of GHG emissions. A report from the National Academies (NRC 2010a) suggests that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of GHGs, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the

[23] GHGs were converted to $MTCO_2e$ using 100-year GWPs from IPCC AR4; the value for CH_4 is 25, while the value for N_2O is 298. This EIS uses AR4 GWPs, as they are now used by most official inventories and inventory guidelines. For example, the United Nations Framework Convention on Climate Change (UNFCCC) requires Annex 1 countries to use the AR4 GWPs in their national GHG inventories. Use of AR4 GWPs also ensures compatibility with EPA's Greenhouse Gas Reporting Program, the president's Climate Action Plan, and the U.S. commitment to GHG emissions reductions submitted to the UNFCCC. While IPCC has updated GWP values in AR5, these newer GWP values have not yet been adopted by national and international inventories and inventory guidelines.

physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As such, efforts to quantify the harm associated with climate change raise serious questions of economics and ethics, and should be viewed as provisional.

The interagency group noted several limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. Additionally, because the estimates for SCC per ton vary over time and are associated with different discount rates and risks, they are intended to be updated as scientific and economic understanding improves. The limited amount of research linking climate impacts to economic damages makes the interagency modeling exercise even more difficult. The interagency group hopes that over time researchers and modelers will work to fill these gaps and that the SCC estimates the Federal Government uses for regulatory analysis will continue to evolve with improvements in modeling. Additional details on these limitations are discussed in the SCC TSD. Even with its limitations, the SCC represents a systematic and thorough approach to summarizing a great deal of scientific and economic information, and Interagency Working Group on Social Cost of Carbon considered the best available information when it came up with these values. Therefore, NHTSA and EPA provide these estimates.

5.3.3 Methods for Estimating Climate Effects

This EIS estimates and reports four effects of climate change driven by alternative scenarios of projected changes in GHG emissions:

- Changes in CO_2 concentrations
- Changes in global temperature
- Changes in precipitation
- Changes in sea level

The change in GHG emissions is a direct effect of the improvements in HD vehicle fuel efficiency associated with the action alternatives; the four impacts on climate change can be considered indirect effects.

Sections 5.3.3.1 through 5.3.3.4 describe the MAGICC modeling, sea level rise methodology, baseline emissions scenario used to represent the No Action Alternative in this analysis, reference case modeling, and climate sensitivity analysis.

5.3.3.1 MAGICC Modeling

This EIS uses a simple climate model (MAGICC) to estimate the changes in CO_2 concentrations and global mean surface temperature, and uses increases in global mean surface temperature combined with an approach and coefficients from the *IPCC WG1 AR5* (IPCC 2013b) to estimate changes in global precipitation. NHTSA used the publicly available modeling software MAGICC6 (Meinshausen et al. 2011) to estimate changes in key direct and indirect effects. NHTSA used MAGICC6 to incorporate the estimated reductions in emissions of CO_2, CH_4, N_2O, CO, NO_x, SO_2, and VOCs produced by the MOVES model (tailpipe) and the associated estimated changes in upstream emissions using the GREET model. NHTSA also performed a sensitivity analysis to examine variations in the direct and indirect climate impacts of the action alternatives under different assumptions about the sensitivity of climate to GHG concentrations in Earth's atmosphere. The results of the sensitivity analysis can be used to infer how

the variation in GHG emissions associated with the action alternatives affects the anticipated magnitudes of direct and indirect climate impacts.

The selection of MAGICC for this analysis was driven by several factors, as follows:

- MAGICC has been used in the peer-reviewed literature to evaluate changes in global mean surface temperature and sea level rise. Applications include the *IPCC WG1 AR5* (IPCC 2013b), where it was used to estimate global mean surface temperature and sea level rise for simulations of global emissions scenarios that were not run with the more complex atmospheric-ocean general circulation models (AOGCMs) (Meinshausen et al. 2011).
- MAGICC is publicly available and was designed for the type of analysis performed in this EIS.
- More complex AOGCMs are not designed for the type of sensitivity analysis performed in this EIS and are best used to provide results for groups of scenarios with much greater differences in emissions.
- MAGICC6 uses updated carbon cycle models that can emulate temperature-feedback impacts on the heterotrophic respiration carbon fluxes.

  MAGICC6 incorporates the science from the *IPCC WG1 AR5;* MAGICC 4.1 was used in the *IPCC WG1 AR4* (IPCC 2007a).[24]

5.3.3.2 Sea-Level Rise

The projected changes in global mean sea level presented in this EIS are estimated based on data from the *IPCC WG1 AR5* (IPCC 2013b).[25] The sea-level rise analysis uses global mean surface temperature data and projections from 1950 to 2100 and global mean sea-level rise projections from 2010 to 2100. These projections are based on the climate ensemble data of the Representative Concentration Pathways (RCP)[26] scenarios for sea level and temperature. Simple equations relating projected changes in sea level to projected changes in temperature are developed for each scenario using a regression model.

The regression models for the RCP4.5 and GCAM6.0 scenarios are developed directly from the RCP4.5 and RCP6.0 data, while the regression model for the GCAM Reference scenario uses a hybrid relation based on the RCP6.0 and RCP8.5 data, as there is no equivalent IPCC scenario. The hybrid relation employs a weighted average of the relationship between RCP6.0 and RCP8.5 sea-level rise and temperature data based on a comparison of the radiative forcings. The temperature outputs of the MAGICC RCP4.5, GCAM6.0, and GCAM Reference simulations are used as inputs to these regression models to project sea-level rise.

5.3.3.3 Global Emissions Scenarios

MAGICC uses long-term emissions scenarios that represent different assumptions about key drivers of GHG emissions. The reference scenario used in this EIS is the GCAM Reference scenario (formerly MiniCAM), which does not assume comprehensive global actions to mitigate GHG emissions. NHTSA selected the GCAM Reference scenario for its incorporation of a comprehensive suite of GHG and

[24] Additional capabilities of MAGICC6 as compared to MAGICC 4.1 include a revised ocean circulation model, improved carbon cycle accounting, direct parameterization of black carbon, organic carbon, and ammonia, and updated radiative forcings. Meinshausen et al. 2011 and Wigley et al. 2009 provide further detail on updates from MAGICC 4.1.

[25] Sea-level rise outputs from MAGICC6 were not used, as this component of the model is still under development.

[26] RCP 2.6, 4.5, 6.0, and 8.5.

pollutant gas emissions, including carbonaceous aerosols and a global context of emissions with a full suite of GHGs and ozone precursors. The GCAM Reference scenario is based on scenarios presented in Clarke et al. (2007), and was used as the basis for the Representative Concentration Pathway RCP4.5, one of the four emissions scenarios defined for IPCC AR5. It uses non-CO_2 and pollutant gas emissions implemented as described in Smith and Wigley (2006); land use change emissions as described in Wise et al. (2009); and updated base-year estimates of global GHG emissions.

In 2003, the U.S. Climate Change Science Program released the *Strategic Plan for the U.S. Climate Change Science Program* (CCSP 2003), which called for the preparation of 21 synthesis and assessment products (SAPs) addressing a variety of topics on climate change science, GHG mitigation, and adapting to the impacts of climate change. These scenarios used updated economic and technology data along with improved scenario development tools that incorporated knowledge gained over the years since the *IPCC Special Report on Emissions Scenarios* (SRES) (IPCC 2000) was released. The strategy recognized that it would be important to have a consistent set of emissions scenarios so that the whole series of SAPs would have the same foundation. Therefore, one of the earliest products in the series —SAP 2.1, Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application (Clarke et al. 2007) —developed 15 global emissions scenarios, corresponding to 5 different emissions trajectories from each of 3 groups using different models (IGSM, MiniCAM, and MERGE). MiniCAM was later renamed GCAM, which is the updated successor to MiniCAM based on improvements in the modeling, and which is the scenario used in this EIS.

Each climate modeling group independently produced a unique emissions reference scenario based on the assumption that no climate policy would be implemented beyond the current set of policies in place using a set of assumptions about drivers such as population changes, economic growth, land and labor productivity growth, technological options, and resource endowments. In addition, each group produced four additional stabilization scenarios, which are defined in terms of the total long-term radiative impact of the suite of GHGs that includes CO_2, N_2O, CH_4, HFCs, PFCs, and SF_6. These stabilization scenarios represent various levels of implementation of global GHG emissions reduction policies.

As explained in more detail below, while the direct and indirect impacts analysis uses the GCAM Reference scenario, the cumulative impacts analysis uses the GCAM 6.0 scenario to represent a Reference Case global emissions scenario, because this scenario assumes substantial global actions to address climate change. Sections 5.3.3.3.1 through 5.3.3.3.3 describe the differences among these scenarios and provide the rationale for use in each analysis.

5.3.3.3.1 Scenario Used for the Direct and Indirect Impacts Analysis

The results of the direct and indirect impacts analysis rely primarily on the GCAM Reference scenario to represent a reference case emissions scenario. The GCAM Reference scenario provides a global context for emissions of a full suite of GHGs and ozone precursors. NHTSA chose the GCAM Reference scenario to present the results of the direct and indirect effects analysis based on the following factors:

- The GCAM Reference scenario is a slightly updated version of the scenario developed by the MiniCAM model of the Joint Global Change Research Institute, a partnership between Pacific Northwest National Laboratory and the University of Maryland. The GCAM Reference scenario is based on a set of assumptions about drivers such as population, technology, and socioeconomic changes, in the absence of global action to mitigate climate change.
- In terms of global emissions of CO_2 from fossil fuels and industrial sources, the GCAM Reference scenario is an updated version of the MiniCAM model scenario and illustrates a pathway of

emissions between the IGSM and MERGE reference scenarios for most of the 21st century. In essence, the GCAM Reference scenario is a "middle-ground" scenario.

- GCAM Reference was evaluated in the Climate Change Science Program's (CCSP) SAP 2.1.

EPA also used the GCAM Reference scenario for the Regulatory Impact Analysis of the joint Phase 1 HD National Program Final Rule and the EPA joint final rule that established CAFE and GHG emissions standards for MY 2017–2021 and MY 2017–2025 light-duty vehicle fleets.

Each action alternative was simulated by calculating the difference between annual GHG emissions under that action alternative and emissions under the No Action Alternative, and subtracting this change from the GCAM Reference scenario to generate modified global-scale emissions scenarios, which show the effects of the various regulatory alternatives on the global emissions path. For example, CO_2 emissions from HD vehicles in the United States in 2020 under the No Action Alternative are estimated to be 706 $MMTCO_2$;[27] the emissions in 2020 under Alternative 3 (Preferred Alternative) are estimated to be 702 $MMTCO_2$. The difference of 4 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global emissions for the GCAM Reference scenario in 2020 are estimated to be 38,017 $MMTCO_2$, and are assumed to incorporate emissions from HD vehicles in the United States under the No Action Alternative. Global emissions under the Preferred Alternative are, therefore, estimated to be 4 $MMTCO_2$ less than this reference level, or approximately 38,013 $MMTCO_2$ in 2020.

There are some inconsistencies between the overall assumptions that SAP 2.1 and the Joint Global Change Research Institute used to develop the global emissions scenario and the assumptions used in the Volpe model in terms of economic growth, energy prices, energy supply, and energy demand. However, these inconsistencies affect the characterization of each action alternative in equal proportion, so the relative estimates provide a reasonable approximation of the differences in environmental impacts among the action alternatives.

5.3.3.3.2 Scenarios Used for the Cumulative Impacts Analysis

The cumulative impacts analysis relies primarily on the GCAM 6.0 scenario to represent a reference case global emissions scenario that assumes substantial global actions to address climate change, as described in greater detail below. NHTSA chose the GCAM 6.0 scenario as a plausible global emissions baseline due to the potential effects of these reasonably foreseeable actions, and assumes a moderate level of global GHG reductions. This reference case global emissions scenario serves as a baseline against which the climate benefits of the various alternatives in this EIS can be measured. For the analysis in this EIS, each action alternative for cumulative impacts was simulated by calculating the difference between annual GHG emissions under that action alternative and emissions under the No Action Alternative and subtracting this change from the GCAM 6.0 scenario to generate modified global-scale emissions scenarios, which shows the effect of the various alternatives on the global emissions path.

NHTSA used the GCAM 6.0 scenario as the primary global emissions scenario for evaluating climate effects in the cumulative impacts analysis. To evaluate the sensitivity of the results to a reasonable range of alternative emissions scenarios, NHTSA also used the Representative Concentration Pathway (RCP) 4.5 scenario and the GCAM Reference emissions scenario. The RCP4.5 scenario is a more

[27] The emissions estimates in this EIS include GHG emissions resulting from HD vehicle fuel combustion (tailpipe emissions), as well as upstream emissions from the production and distribution of fuel.

aggressive stabilization scenario that illustrates the climate system response to stabilizing the anthropogenic components of radiative forcing at 4.5 watts per square meter in 2100.

The GCAM 6.0 scenario is the GCAM representation of the radiative forcing target (6.0 watts per square meter) of the (RCP) scenarios developed by the MiniCAM model of the Joint Global Change Research Institute. The GCAM 6.0 scenario assumes a moderate level of global GHG reductions. It is based on a set of assumptions about drivers such as population, technology, socioeconomic changes, and global climate policies that correspond to stabilization, by 2100, of total radiative forcing and associated CO_2 concentrations at roughly 678 ppm. More specifically, GCAM 6.0 is a scenario that incorporates declines in overall energy use, including fossil fuel use, as compared to the reference case. In addition, GCAM 6.0 includes increases in renewable energy and nuclear energy. The proportion of total energy use supplied by electricity also increases over time due to fuel switching in end-use sectors. CO_2 capture and storage also plays an important role that allows for continued use of fossil fuels for electricity generation and cement manufacture while limiting CO_2 emissions. Although GCAM 6.0 does not explicitly include specific climate change mitigation policies, it does represent a plausible future pathway of global emissions in response to substantial global action to mitigate climate change.

Using the GCAM 6.0 scenario as described above, total emissions from HD vehicles in the United States in 2020 under the No Action Alternative are estimated to be 706 $MMTCO_2$; emissions in 2020 under the Preferred Alternative are estimated to be 702 $MMTCO_2$. The difference of 4 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global CO_2 emissions for the GCAM 6.0 scenario in 2020 are estimated to be 37,522 $MMTCO_2$ and are assumed to incorporate the level of emissions from HD vehicles in the United States under the No Action Alternative. Global emissions under the Preferred Alternative are, therefore, estimated to be 4 $MMTCO_2$ less than this reference level, or 37,518 $MMTCO_2$ in 2020 under the cumulative impacts analysis.

5.3.3.3.3 Past, Present, and Reasonably Foreseeable Future Actions Related to the Cumulative Impacts Analysis

NHTSA chose the GCAM 6.0 scenario as the primary global emissions scenario for evaluating climate effects for this chapter because regional, national, and international initiatives and programs now in the planning stages and underway indicate that a moderate reduction in the growth rate of global GHG emissions is reasonably foreseeable in the future.

The initiatives and programs discussed below are those that NHTSA has determined are relevant to its consideration of past, present, or reasonably foreseeable actions to reduce GHG emissions. NHTSA used this scenario to assess the impacts of the action alternatives when reasonably foreseeable reductions in global GHG emissions are taken into account. Although it is not possible to quantify the precise GHG reductions associated with these actions, policies, or programs when taken together (and NHTSA does not attempt to do so), collectively they illustrate an existing and continuing trend of U.S. and global awareness, emphasis, and efforts toward substantial GHG reductions. They imply that future commitments for reductions are probable. Therefore, a scenario that accounts for moderate reductions in the rate of global GHG emissions, such as the GCAM 6.0 scenario, can be considered reasonably foreseeable under NEPA.

<u>United States: Regional Actions</u>

- **Regional Greenhouse Gas Initiative (RGGI)**. Launched in January 1, 2009, RGGI was the first mandatory, market-based effort in the United States to reduce GHG emissions (RGGI 2009). Nine northeastern and Mid-Atlantic States (Connecticut, Delaware, Maine, Maryland, Massachusetts,

New Hampshire, New York, Rhode Island, and Vermont) agreed to cap annual emissions from power plants in the region at 188 $MMTCO_2$ for 2009 through 2011, and 165 $MMTCO_2$ for 2012 through 2013 (RGGI 2014 and Rutgers 2014). In 2013, the RGGI states lowered the Regional Emissions Cap to 91 $MMTCO_2$ for 2014. The RGGI CO_2 cap then declines 2.5 percent per year from 2015 through 2020 (RGGI 2014). By 2020, the program is projected to have avoided 80 to 90 $MMTCO_2$ (C2ES 2014c).

- **California Global Warming Solutions Act of 2006 (AB 32)**. California's major initiatives for reducing GHG emissions are implemented under Assembly Bill (AB) 32, which requires California to reduce emissions to 1990 levels by 2020, and then reduce emissions by 80 percent below 1990 levels by 2050. These initiatives will reduce GHGs from cars, trucks, electricity production, fuels, and other sources. GHG-reduction measures include low carbon fuel standards, a GHG cap-and-trade program, and appliance efficiency standards (CARB 2014). The cap-and-trade program is a key element of AB 32, setting a statewide limit on GHG sources accounting for 85 percent of statewide emissions. The cap-and-trade program took effect in 2013 for electric generation units and large industrial facilities and expands in 2015 to include ground transportation and heating fuels (C2ES 2014b).

United States: Federal Actions

- **Standards of Performance for GHG Emissions from New Stationary Sources: Electric Utility Generating Units**. In March 2012, EPA proposed a new standard for allowable carbon emissions from new stationary electric power sources. In September 2013, EPA released a revised proposal changing some aspects of its approach; this proposal was published in the *Federal Register* in January 2014. If finalized as proposed, the standards will apply to a new facility that supplies more than one-third of its potential electric output and more than 219,000 megawatt-hours (MWh) net electric output to the grid per year. GHG emissions from new fossil-fuel-fired boilers and integrated gasification combined cycle (IGCC) units would be capped at 1,100 pounds of CO_2 per MWh gross output over a 12-operating month period or 1,000-1,050 pounds of CO_2 per MWh output over an 84-operating month (7-year) period. Performance standards for new boilers and new IGCC units are based on partial capture of CO_2 from the unit. New natural-gas-fired stationary combustion units would be capped at 1,000 pounds of CO_2 per MWh of gross output for larger units (more than 850 million British thermal units per hour [mmBtu/hr] or 250 megawatts [MW]) and would be capped at 1,100 pounds of CO_2 per MWh of gross output for smaller units (less than 850 mmBtu/hr or 250 MW). EPA has not set a deadline for finalizing the standard. However, it must be finalized before EPA finalizes its guidelines for existing power plants, currently planned to be released by mid-summer 2015.
- **Standards of Performance for GHG Emissions for Existing Stationary Sources: Electric Utility Generating Units (known as the Clean Power Plan)**. EPA released a proposed rule on June 2, 2014 to regulate CO_2 emissions from existing power plants. Existing units are defined as those that were in operation or had commenced construction as of January 8, 2014. The proposal would require states to meet CO_2 emissions targets starting in 2020 on a state-wide basis. The proposed rule is expected to reduce CO_2 emissions from existing power plants to 30 percent below 2005 levels by 2030. State targets proposed by EPA vary widely based on the "unique mix of emissions and power sources" in each state. EPA gives states the option to convert rate-based targets into mass-based goals. EPA plans on releasing a final rule by summer 2015, and will require states to submit their state implementation plans (SIPs) by summer 2016 (EPA 2015). However, extensions for SIP submittal of up to 1 year may be granted upon request, and an extension of up to 2 years may be granted to states that are implementing a multi-state plan. In January 2015, EPA also began the

regulatory process to develop a federal implementation plan for meeting the Clean Power Plan goals in areas that do not submit plans. EPA expects to release a final federal plan in summer 2016.

- **NHTSA and EPA Joint Rule on GHG Emissions and Fuel Economy Standards for Light-Duty Vehicles**. In August 2012, NHTSA and EPA issued joint Final Rules to extend the National Program for GHG emissions and fuel economy standards into its third phase, generally applying to MYs 2017–2025. NHTSA issued CAFE standards under the Energy Policy and Conservation Act (EPCA), as amended by the Energy Independence and Security Act (EISA), and EPA issued GHG emissions standards under the Clean Air Act (CAA). Vehicles covered by these standards are responsible for almost 60 percent of all U.S. transportation-related GHG emissions. The CAFE standards are projected to increase fuel economy to the equivalent of 54.5 miles per gallon (mpg) and 163 grams per mile of CO_2 for MY 2025 vehicles. The new standards are projected to reduce CO_2 emissions from the U.S. light-duty vehicle fleet by 3.5 percent per year for MYs 2017–2021, and 5 percent per year for MYs 2022–2025 (NHTSA and EPA 2011). The combined National Program is expected to cut 6 billion metric tons of GHGs over the lifetime of vehicles sold in MYs 2012–2025 (EPA 2012).
- **NHTSA and EPA Joint Rule on GHG Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Vehicles, MYs 2014–2018**. On September 15, 2011, NHTSA and EPA published the Phase 1 joint Final Rules to establish fuel efficiency and GHG standards for HD vehicles. The rules together comprise a coordinated and comprehensive HD National Program and result in substantial improvements in fuel efficiency and reductions in GHG emissions. The agencies' standards apply to highway vehicles and engines that are not regulated by the passenger car, light-duty truck, and medium-duty passenger vehicle CAFE and GHG standards. NHTSA's Phase 1 mandatory standards for HD vehicles and engines will begin for MY 2016 vehicles, with voluntary standards for MYs 2014–2015. EPA's mandatory standards for HD vehicles began for MY 2014 vehicles. The agencies estimate that the combined standards will reduce CO_2 emissions by approximately 270 million metric tons and save 530 million barrels of oil over the life of vehicles built during MYs 2014–2018.
- **Renewable Fuel Standard 2 (RFS2)**. Section 211(o) of the CAA requires that a renewable fuel standard be determined annually that is applicable to refiners, importers, and certain blenders of gasoline. On the basis of this standard, each regulated party determines the volume of renewable fuel that it must ensure is consumed as motor vehicle fuel. RFS2, which went into effect July 1, 2010, increases the volume of renewable fuel required to be blended into gasoline from the baseline of 9 billion gallons in 2008 to 36 billion gallons by 2022. EPA estimates that the greater volume of biofuel mandated by RFS2 will reduce life-cycle GHG emissions by an annual average of 138 million tons of CO_2e in 2022. As of November 2013, the proposed renewable fuel standard for 2014 was 9.20 percent (EPA 2013a).
- **United States GHG Emissions Target in Association with the Copenhagen Accord**. Building on the pledge made at the December 2009 United Nations climate change conference in Copenhagen (COP-15), President Obama submitted to the United Nations Framework Convention on Climate Change (UNFCCC) a GHG target for the United States in the range of 17 percent below 2005 levels by 2020. At the December 2011 United Nations climate change conference in Durban, South Africa (COP-17), the United States reiterated this commitment (U.S. Department of State 2011). Among other initiatives, recent federal actions that are expected to reduce GHG emissions include a $90 billion investment in clean energy through the American Recovery and Reinvestment Act of 2009, and development of wind energy on the Outer Continental Shelf. On March 31, 2015, the State Department submitted the U.S. Intended Nationally Determined Contribution (INDC) to reduce GHG emissions. The U.S. economy-wide INDC aims to reduce GHG emissions by 26 to 28 percent below 2005 levels by 2025, while also pledging to make best efforts to achieve the higher reduction target of 28 percent below 2005 levels by 2025.

- **United States Appliance and Equipment Standards Program**. The National Appliance Energy Conservation Act of 1987 established minimum efficiency standards for many household appliances and is authorized by Congress through several statutes. Since its inception, the program has implemented standards for more than 50 products, which represent about 90 percent of home energy use, 60 percent of commercial building use, and 29 percent of industrial energy use (DOE 2014a). Annual CO_2 savings will reach over 275 million tons of CO_2 by 2020 and the program will have cumulatively avoided 6.8 billion tons by 2030 (DOE 2014b).

International Actions

- **United Nations Framework Convention on Climate Change – The Kyoto Protocol and the annual Conference of the Parties (COP)**. The UNFCCC is an international treaty signed by many countries around the world (including the United States), which entered into force on March 21, 1994, and sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change (UNFCCC 2002).

  Kyoto Protocol: The Kyoto Protocol is an international agreement linked to the UNFCCC. The major feature of the Kyoto Protocol is its binding targets for 37 industrialized countries and the European Community for reducing GHG emissions, which covers more than half of the world's GHG emissions. These reductions amount to approximately 5 percent of 1990 emissions over the 5-year period 2008 through 2012 (UNFCCC 2014a). The December 2011 COP-17 held in Durban, South Africa, resulted in an agreement to extend the soon-to-expire Kyoto Protocol. The "Second Commitment Period" went into effect on January 1, 2013 and runs through December 2020, and requires Parties to reduce emissions by at least 18 percent below 1990 levels by 2020; the Parties in the second commitment period differ from those in the first (UNFCC 2014a).

  Additional Decisions and Actions: At COP-16, held in Cancun, Mexico in December 2010, a draft accord pledged to limit global temperature increase to less than 2°C (3.6°F) above pre-industrial global average temperature. At COP-17, the Parties established the "Working Group on the Durban Platform for Enhanced Action" to develop a protocol for mitigating emissions from rapidly developing countries no later than 2015, and to take effect in 2020 (UNFCCC 2014b). As of April 12, 2012, 141 countries have agreed to the Copenhagen Accord, accounting for the vast majority of global emissions (UNFCCC 2010). However, the pledges are not legally binding, and much remains to be negotiated. At COP-18, held in Doha, Qatar in November 2012, the parties also made a long-term commitment to mobilize $100 billion per year to the Green Climate Fund by 2020, which will operate under the oversight of the COP to support climate change-related projects around the world (UNFCC 2012). At COP-19, held in Warsaw, Poland in November 2013, key decisions were made towards the development of a universal 2015 agreement in which all nations would bind together to rapidly reduce emissions, build adaptation capacity, and stimulate faster and broader action (UNFCCC 2014b). COP-19 also marked the opening of the Green Climate Fund, which began its initial resource mobilization process in 2014 (UNFCCC 2014c). At COP-20 held in Lima, Peru in December 2014, countries agreed to submit INDCs (country-specific GHG mitigation targets) by the end of the first quarter of 2015. COP-20 also increased transparency of GHG reduction programs in developing countries through a Multilateral Assessment process, elicited increased pledges to the Green Climate Fund, made National Adaptation Plans more accessible on the UNFCCC website, and called on governments to increase educational initiatives around climate change (UNFCCC 2014d).
- **The European Union GHG Emissions Trading System (ETS)**. In January 2005, the European Union ETS commenced operation as the largest multi-country, multi-sector GHG emissions trading system worldwide (European Union 2014). The aim of the ETS is to help European Union member states

achieve compliance with their commitments under the Kyoto Protocol (European Union 2005). This trading system does not entail new environmental targets; instead, it allows for less expensive compliance with existing targets under the Kyoto Protocol. The scheme is based on Directive 2003/87/EC, which entered into force on October 25, 2003 (European Union 2005) and covers more than 11,000 energy-intensive installations across the European Union. This represents almost half of Europe's emissions of CO_2 (European Union 2014). These installations include commercial aviation, combustion plants, oil refineries, and iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp, and paper (European Union 2014). The EU projects that emissions from sources covered by this program will decrease by 43 percent in 2030 compared to emissions in 2005 (European Union 2014).

- **Fuel Economy Standards in Asia**. Both Japan and China have taken actions to reduce fuel use, CO_2 emissions, and criteria pollutant emissions from vehicles. Japan has invested heavily in research and development programs to advance fuel-saving technologies, has implemented fiscal incentives such as high fuel taxes and differential vehicle fees, and has mandated fuel economy standards based on vehicle weight class (using country-specific testing procedures [Japan 1015/JC08]). As such, Japan adopted efficiency standards for HD vehicles in 2005, with standards to be fully implemented in 2015 (GFEI 2014). Additionally, Japan set a 2020 target for light duty vehicles to have an average fuel economy of 20.3 km/L (47.7 mpg), a 24.1 percent improvement from 2010 standards (IPEEC 2014). Similarly, China has implemented fuel economy standards, modeled after European Union standards (using the New European Driving Cycle testing methods). In 2013, China adopted its first national fuel efficiency standards for HD vehicles; the program is scheduled to take effect for MY 2015 vehicles. China has also implemented research and development programs, differential vehicle fees, and technology mandates (UN 2011).

5.3.3.4 Reference Case Modeling Runs

The modeling runs and sensitivity analysis simulate relative changes in atmospheric concentrations, global mean surface temperature, precipitation, and sea-level rise that could result under each alternative.

The modeling runs are based on the reductions in emissions estimated to result from each of the action alternatives for both the direct and indirect and cumulative impacts analyses. They assume a climate sensitivity of 3°C (5.4°F) for a doubling of CO_2 concentrations in the atmosphere. The approach uses the following four steps to estimate these changes:

1. NHTSA assumed that global emissions under the No Action Alternative follow the trajectory provided by the global emissions scenario.
2. Global emissions for each action alternative were assumed to be equal to the global emissions under the No Action Alternative minus the reductions in emissions of CO_2, CH_4, N_2O, SO_2, NO_x, CO, and VOCs estimated to result from each action alternative (for example, the global emissions scenario under Alternative 2 equals the global emissions scenario minus the emissions reductions from that alternative). All SO_2 reductions were applied to the Aerosol region 1 of MAGICC, which includes North America.
3. NHTSA used MAGICC6 to estimate the changes in global CO_2 concentrations, global mean surface temperature, and sea-level rise through 2100 using the global emissions scenario under each alternative developed in steps 1 and 2.
4. NHTSA used the increase in global mean surface temperature to estimate the increase in both global average precipitation and sea-level rise for each alternative using the global emissions scenario.

5.3.3.5 Sensitivity Analysis

NHTSA performed a sensitivity analysis to examine the effect of various equilibrium climate sensitivities on the results. Equilibrium climate sensitivity is the projected responsiveness of Earth's global climate system to increased radiative forcing from higher GHG concentrations and is expressed in terms of changes to global surface temperature resulting from a doubling of CO_2 compared to pre-industrial atmospheric concentrations (278 ppm CO_2) (IPCC 2013b). Sensitivity analyses examine the relationship among the alternatives, likely climate sensitivities, and scenarios of global emissions paths and the associated direct and indirect impacts for each combination.

The IPCC AR5 expresses stronger confidence in some fundamental processes in models that determine climate sensitivity than the AR4 (IPCC 2013b). According to the IPCC, with a doubling the concentration of atmospheric CO_2, there is a *likely* probability of an increase in surface warming in the range 1.5°C (2.7°F) to 4.5°C (8.1°F) [*high confidence*], *extremely unlikely* less than 1°C (1.8°F) [*high confidence*], and *very unlikely* greater than 6°C (10.8°F) [*medium confidence*] (IPCC 2013b).

NHTSA assessed climate sensitivities of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0°C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8°F) for a doubling of CO_2 concentrations in the atmosphere. NHTSA performed the sensitivity analysis around two of the alternatives—the No Action Alternative and the Preferred Alternative—because this was deemed sufficient to assess the effect of various climate sensitivities on the results.

The approach uses the four steps listed below to estimate the sensitivity of the results to alternative estimates of the climate sensitivity:

1. NHTSA used the GCAM Reference scenario for the direct and indirect impacts analysis and the GCAM 6.0 scenario for the cumulative impacts analysis to represent emissions from the No Action Alternative.
2. Starting with the respective GCAM scenario, NHTSA assumed that the reductions in global emissions of CO_2, CH_4, N_2O, SO_2, NOx, CO, and VOCs resulting from the Preferred Alternative are equal to the global emissions of each pollutant under the No Action Alternative minus emissions of each pollutant under the Preferred Alternative. All SO_2 reductions were applied to Aerosol region 1 of MAGICC, which includes North America.
3. NHTSA assumed a range of climate sensitivity values consistent with the 10 to 90 percent probability distribution from the IPCC WG1 AR5 (IPCC 2013b) of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0°C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8°F).
4. For each climate sensitivity value in step 3, NHTSA used MAGICC6 to estimate the resulting changes in CO_2 concentrations and global mean surface temperature, as well as the regression-based analysis to estimate sea-level rise through 2100 for the global emissions scenarios in steps 1 and 2.

Section 5.4 presents the results of the model runs for the alternatives. For the direct and indirect impacts analysis, the sensitivity analysis was performed against the GCAM Reference scenario (789 ppm in 2100). For the cumulative impacts analysis, the sensitivity analysis also assesses the sensitivity around different global emissions scenarios. NHTSA assumed multiple global emissions scenarios including GCAM 6.0 (687 ppm in 2100); RCP4.5 (544 ppm in 2100); and GCAM Reference scenario (789 ppm in 2100). Section 5.4.2.3.5 presents the results of the cumulative impacts sensitivity analysis for these different global emissions scenarios.

5.3.4 Tipping Points and Abrupt Climate Change

The phrase tipping point is most typically used, in the context of climate change and its consequences, to describe situations in which the climate system (the atmosphere, hydrosphere, land, cryosphere, and biosphere) reaches a point at which a disproportionally large or singular response in a climate-affected system occurs as a result of only a moderate additional change in the inputs to that system (such as an increase in the CO_2 concentration). Exceeding one or more tipping points, which "occur when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause" (EPA 2009 citing NRC 2002), could result in abrupt changes in the climate or any part of the climate system. Abrupt climate changes could occur so quickly and unexpectedly that human systems would have difficulty adapting to them (EPA 2009 citing NRC 2002).

NHTSA's assessment of tipping points and abrupt climate change is largely based on an analysis of recent climate change science synthesis reports: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013b) and Climate Change Impacts in the United States: The Third National Climate Assessment (GCRP 2014). The analysis identifies vulnerable systems, potential thresholds, and estimates of the causes, likelihood, timing, and impacts of abrupt climate events.

Although there are methodological approaches to estimate changes in temperatures resulting from a reduction in GHG emissions and associated radiative forcing, the current state of science does not allow for quantifying how emissions reductions from a specific policy or action might affect the probability and timing of abrupt climate change. This area of climate science is one of the most complex and scientifically challenging. Given the difficulty of simulating the large-scale processes involved in these tipping points, or inferring their characteristics from paleoclimatology, considerable uncertainties remain on tipping points and the rate of change. Despite the lack of a precise quantitative methodological approach, NHTSA has provided a qualitative and comparative analysis of tipping points and abrupt climate change in Section 5.5.1.10 of this EIS. The analysis applies equally to the direct and indirect impacts discussion and the cumulative impacts discussion given that tipping points are best viewed in the perspective of long-term, large-scale global trends.

5.4 Environmental Consequences

This section describes projected impacts on climate under the Proposed Action and the alternatives considered. Using the methodologies described in Section 5.3, NHTSA modeled the effects of the Proposed Action on atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise. To calculate the incremental benefits of the Proposed Action, NHTSA examined the direct and indirect impacts of the action alternatives, which were developed by using the analytical methodologies described in Chapter 2. The methodologies used to estimate the climate-related impacts of the Proposed Action and alternatives are summarized in Section 5.3.

Section 5.4 is organized into Section 5.4.1, *Direct and Indirect Impacts*, and Section 5.4.2, *Cumulative Impacts*. Within each, there are sub-sections for greenhouse gas emissions, the social cost of carbon, and impacts on climate change indicators. The analysis of direct and indirect impacts in Section 5.4.1 is based on a scenario under which there are no other major global actions to reduce GHGs. This analysis assumes that there is some growth in HD vehicle fuel efficiency in the absence of the Proposed Action, with no ongoing improvements in new vehicle fuel efficiency after the final year of stringency increases. This section presents the results of the analysis of the alternatives. The analysis compares the alternatives to the current climate trajectory, independent of other actions.

The analysis of cumulative impacts in Section 5.4.2 measures the combined impacts of market-based incentives for improving HD vehicle fuel efficiency after 2018 and the HD vehicle fuel efficiency improvements resulting directly or indirectly from the Proposed Action and alternatives. This analysis generally assumes no improvement in future HD vehicle fuel efficiency in the absence of the Proposed Action and no ongoing improvements in new vehicle fuel efficiency after the final year of stringency increases. For assessing climate impacts, the analysis in Section 5.4.2 is broader in that it addresses the effects of the proposed standards in concert with the effects of other past, present, and reasonably foreseeable future actions that affect the current climate trajectory.

5.4.1 *Direct and Indirect Impacts*

This section describes the environmental consequences of the Proposed Action alternatives on GHG emissions and climate effects.

5.4.1.1 Greenhouse Gas Emissions

Using the methodology described in Section 5.3, NHTSA estimated projected emissions reductions under the Proposed Action and alternatives for 2018 through 2100. The emissions reductions in the following discussion represent the differences in total annual emissions in future years of U.S. HD vehicles in use under the No Action Alternative and each action alternative. The projected change in fuel production and use under each alternative determines the resulting impacts on total energy use and petroleum consumption, which in turn determine the reduction in CO_2 emissions under each alternative. Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use—more than 95 percent, even after accounting for the higher GWPs of other GHGs— NHTSA's consideration of GHG impacts focuses on reductions in CO_2 emissions expected under the action alternatives. However, in assessing the direct and indirect impacts and cumulative impacts on climate change indicators, as described in Sections 5.4.1.3 and 5.4.2.3, NHTSA incorporates reductions of all GHGs.

Table 5.4.1-1 and Figure 5.4.1-1 show total U.S. HD vehicle CO_2 emissions under the No Action Alternative and emissions reductions that would result from each of the action alternatives from 2018 to 2100. U.S. HD vehicle emissions for this period range from a low of 59,400 $MMTCO_2$ under Alternative 5 up to 73,600 $MMTCO_2$ under the No Action Alternative. Compared to the No Action Alternative, projected emissions reductions from 2018–2100 under the action alternatives range from 5,500 to 14,200 $MMTCO_2$.

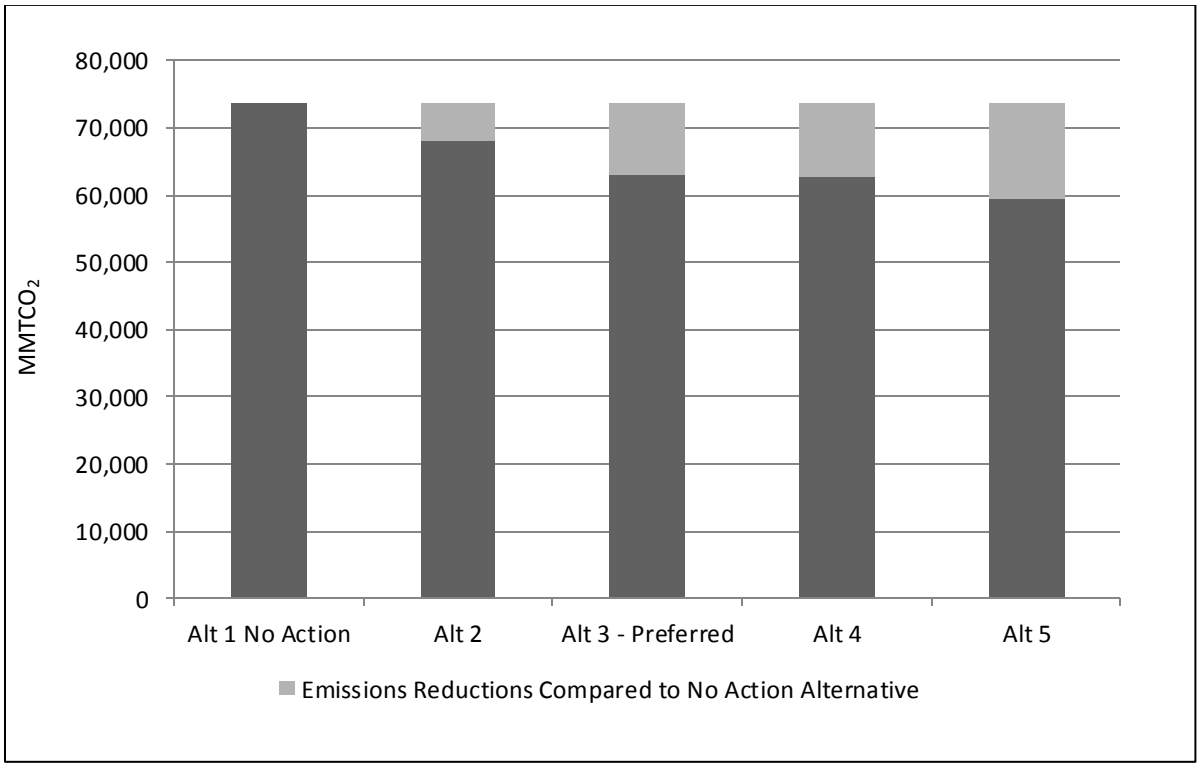
Table 5.4.1-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles, 2018–2100 by Alternative[a]

Alternative	Total Emissions	Emissions Reductions Compared to No Action	Percent (%) Emissions Reductions Compared to No Action Emissions
Alt. 1 – No Action	73,600		
Alt. 2	68,100	5,500	7
Alt. 3 – Preferred	62,900	10,800	15
Alt. 4	62,600	11,000	15
Alt. 5	59,400	14,200	19

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

Figure 5.4.1-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles, 2018 to 2100 by Alternative



Compared to total global emissions of 5,063,078 $MMTCO_2$ over this period (projected by the GCAM Reference scenario), the Proposed Action is expected to reduce global CO_2 emissions by approximately 0.1 to 0.3 percent from their projected levels under the No Action Alternative.

To get a sense of the relative impact of these reductions, it can be helpful to consider emissions from HD vehicles in the context of emissions projections from the transportation sector and expected or stated goals from existing programs designed to reduce CO_2 emissions. HD vehicles currently account for 7.5 percent of CO_2 emissions in the United States. The action alternatives reduce total CO_2 emissions from U.S. HD vehicles by a range of 7 to 19 percent in the period from 2018 to 2100 compared to the No Action Alternative. Compared to total U.S. CO_2 emissions by the end of the century from all sources of the 7,193 $MMTCO_2$ projected by the GCAM Reference scenario (Thomson et al. 2011), the action alternatives would reduce total U.S. CO_2 emissions by a range of 1.0 to 2.6 percent in 2100.[28] shows the projected annual emissions from U.S. HD vehicles under the alternatives.

[28] 2095 is the last year emissions data is available from GCAM Reference.

Figure 5.4.1-2. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative

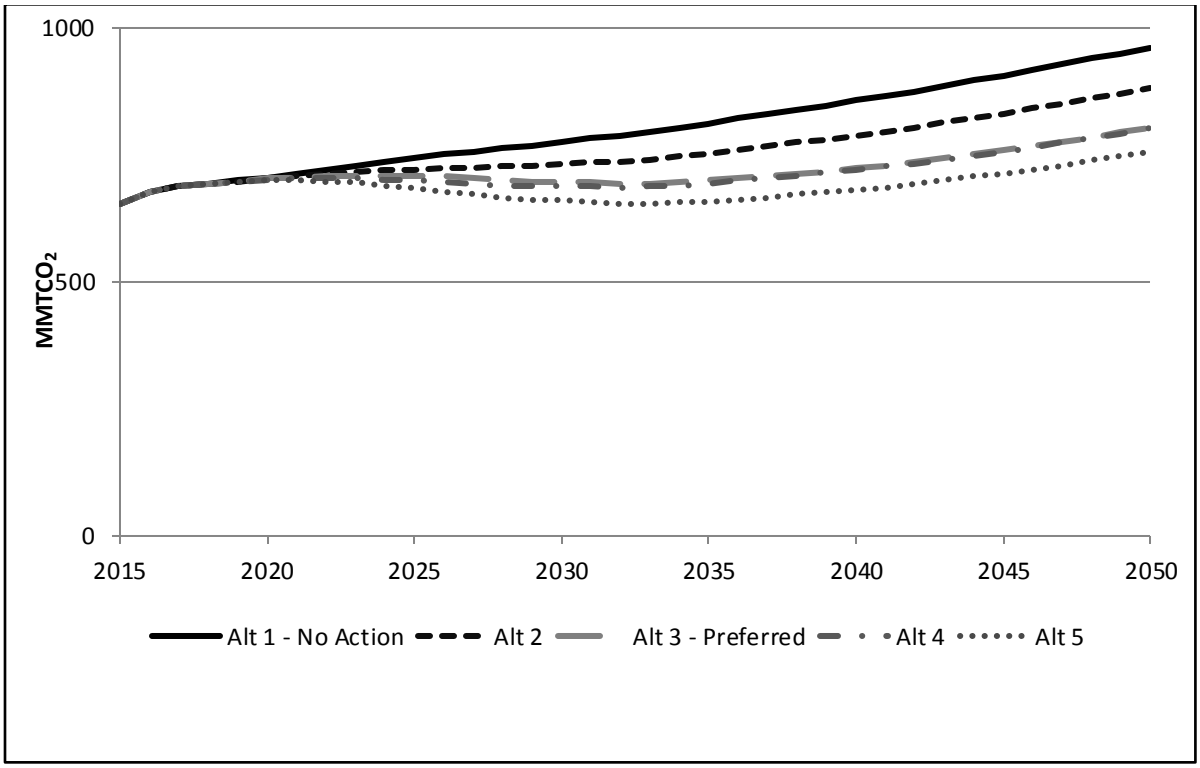


Table 5.4.1-2 shows that under the No Action Alternative, total CO_2, CH_4, and N_2O emissions from HD vehicles in the United States are projected to substantially increase between 2018 and 2100 in the direct/indirect analysis. Growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use, is projected to result in a growth in VMT. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles.

Table 5.4.1-2 also illustrates that each action alternative would reduce HD vehicle emissions of CO_2 from their projected levels under the No Action Alternative. Similarly, under each of the action alternatives, CH_4 emissions in future years are projected to decline from their projected levels under the No Action Alternative. Progressively larger reductions in CO_2 emissions from their levels under the No Action Alternative are projected under Alternatives 2 through 5, because the action alternatives require progressively larger increases in fuel economy.

Table 5.4.1-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year)[a] from All HD Vehicles by Alternative[b]

GHG and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon dioxide (CO_2)					
2020	706	703	702	702	701
2040	856	788	723	720	680
2060	957	877	798	797	751
2080	950	871	793	791	746
2100	884	810	737	736	694
Methane (CH_4)					
2020	19.36	19.29	19.27	19.26	19.24
2040	23.85	21.18	19.34	19.26	18.07
2060	26.63	23.48	21.28	21.24	19.86
2080	26.45	23.31	21.13	21.09	19.72
2100	24.60	21.68	19.65	19.61	18.34
Nitrous oxide (N_2O)					
2020	2.13	2.12	2.12	2.12	2.12
2040	2.25	2.14	2.02	2.00	1.94
2060	2.46	2.34	2.19	2.18	2.11
2080	2.45	2.32	2.18	2.16	2.09
2100	2.27	2.16	2.02	2.01	1.95
Total (all GHGs)					
2020	727	725	724	723	723
2040	882	811	744	741	700
2060	986	903	822	820	773
2080	979	896	816	815	768
2100	910	834	759	758	714

Notes:

[a] $MMTCO_2e$ = million metric tons carbon dioxide equivalent.

[b] Emissions from 2051–2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the GCAM Reference scenario. These assumptions project a slight decline over this time period.

5.4.1.1.1 Comparison to the 2020 and 2025 U.S. GHG Targets Submitted to the United Nations Framework Convention on Climate Change

These results can be viewed in light of U.S. GHG emissions reduction targets. In 2010, President Obama submitted to the UNFCCC a GHG emissions reduction target for the United States in the range of 17 percent below 2005 levels by 2020, in association with the Copenhagen Accord. On March 31, 2015, President Obama submitted an "Intended Nationally Determined Contribution" (INDC) to reduce U.S. GHG emissions in the range of 26 to 28 percent below 2005 levels by 2025. The INDC also pledges that the United States will make best efforts to achieve the higher reduction target of 28 percent below 2005 levels by 2025.

Although the action alternatives would reduce projected CO_2 emissions in 2020 compared to what they would otherwise be without action, total CO_2 emissions from the U.S. HD vehicle sector in 2020 and 2025 are projected to be above 2005 levels. Therefore, assuming the same percentage decrease in

emissions would need to be achieved from all sectors in order to reach the president's target, these reductions in emissions alone would not reduce total HD vehicle emissions to 17 percent below their 2005 levels by 2020, or 26 to 28 percent below 2005 levels by 2025.

The president's targets outlined above do not specify that every emitting sector of the economy must contribute equally proportional emissions reductions. Thus, smaller emissions reductions in the HD vehicle sector can be compensated for by larger reductions in other sectors. In addition, the action of setting fuel economy standards does not directly regulate total emissions from HD vehicles. NHTSA's authority to promulgate new HD vehicle fuel efficiency standards does not allow the agency to regulate other factors affecting emissions, such as HD vehicle driving habits or use trends; NHTSA cannot, for example, control VMT. Under all of the alternatives, growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use (annual VMT per vehicle) due to economic improvement and a variety of other factors, is projected to result in growth in HD vehicle VMT.

This projected growth in travel between 2020 and 2050 more than offsets the effect of improvements in HD vehicle fuel efficiency for all the alternatives due to increases in fuel consumption from HD vehicles. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles. Nevertheless, the Proposed Action is an important component of a variety of actions in various sectors to meet the U.S. GHG targets.

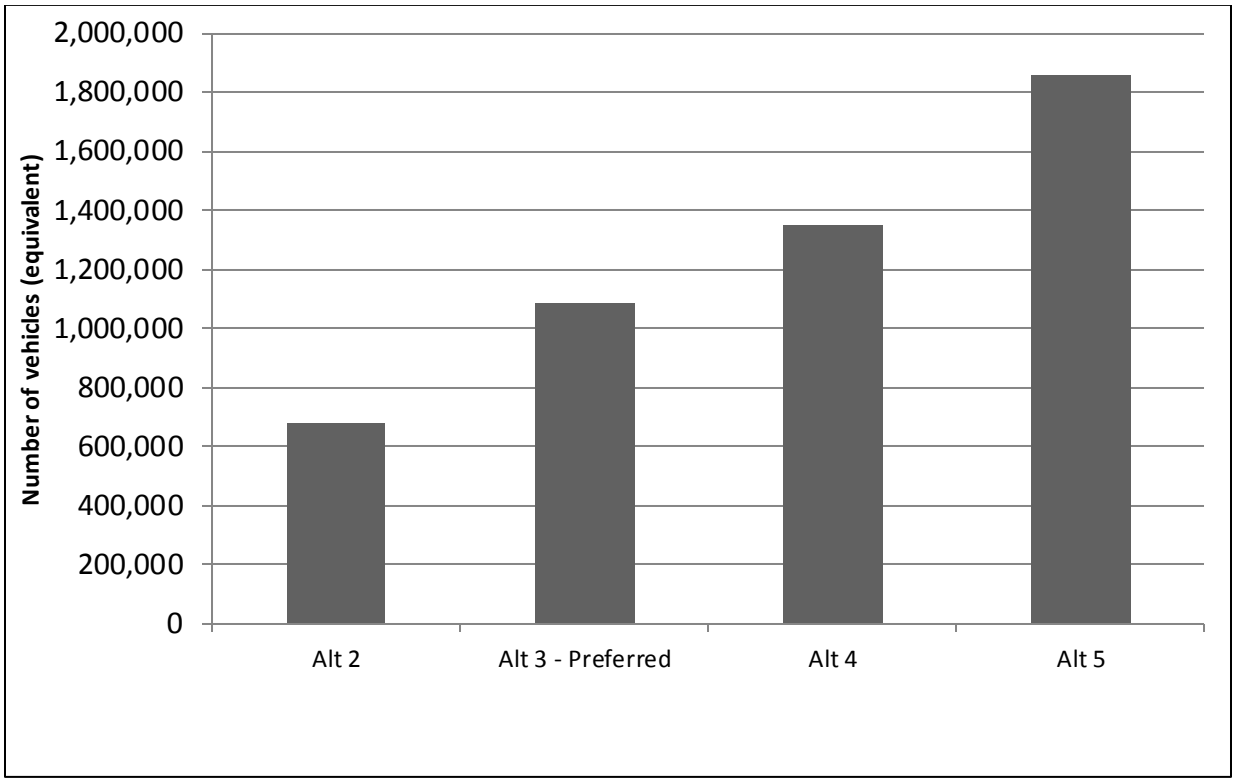
5.4.1.1.2 Comparison to Annual Emissions from HD Vehicles

As an illustration of the fuel savings projected under the action alternatives, Figure 5.4.1-3 expresses the CO_2 reductions under each action alternative in 2025 as the equivalent number of HD vehicles that would produce those emissions in that year. The emissions reductions under the action alternatives are equivalent to the annual emissions of between 678,000 HD vehicles (Alternative 2) and 1.86 million HD vehicles (Alternative 5) in 2025, compared to the annual emissions that would occur under the No Action Alternative. Emissions reductions in 2025 under the Preferred Alternative are equivalent to annual emissions of 1.09 million HD vehicles.

These annual CO_2 reductions, their equivalent in HD vehicles, and differences among alternatives grow larger in future years as older HD vehicles continue to be replaced by newer ones that meet the increasingly stringent fuel efficiency standards required under each alternative.[29]

[29] The HD vehicle equivalency is based on an average per-vehicle emissions estimate, which includes both tailpipe CO_2 emissions and associated upstream emissions from fuel production and distribution. The average HD vehicle accounts for 32.28 metric tons of CO_2 in 2025 based on MOVES and GREET model analysis.

Figure 5.4.1-3. Number of HD Vehicles Equivalent to CO_2 Reductions in 2025, Compared to the No Action Alternative



5.4.1.1.3 Comparison to GHG Reduction Programs in the United States

To understand the projected emissions reductions from the alternatives better, the reductions can also be compared to existing programs that have been designed to reduce GHG emissions in the United States.

In June 2014, EPA released a proposed rule, known as the Clean Power Plan, under Section 111(d) of the Clean Air Act to regulate CO_2 emissions from existing power plants. The proposed rule will cover 3,000 coal electric generation units and is expected to reduce CO_2 emissions from existing power plants to 30 percent below 2005 levels in the year 2030, equivalent to 730 $MMTCO_2e$. EPA expects to release a final federal plan in the summer of 2016 (EPA 2014).

California's major initiatives for reducing GHG emissions are implemented under AB 32, which requires California to reduce emissions to 1990 levels by 2020, then reduce emissions by 80 percent below 1990 levels by 2050. GHG reduction measures include low-carbon fuel standards, a GHG cap-and-trade program, and appliance efficiency standards (CARB 2014). The cap-and-trade program is a key element of AB 32, setting a statewide limit on GHG sources accounting for 85 percent of statewide emissions. The cap-and-trade program took effect in 2013 for electric generation units and large industrial facilities and expands in 2015 to include ground transportation and heating fuels (C2ES 2014a).

Elsewhere in the United States, the nine RGGI member states in the northeast and mid-Atlantic regions set a goal to cap annual CO_2 emissions from power plants in the northeast beginning in 2009 (C2ES 2014b). For example, the RGGI set a Regional Emissions Cap of 91 $MMTCO_2$ for 2014; the cap then declines 2.5 percent per year from 2015 to 2020 (RGGI 2014). In 2020, the program is projected to reduce emissions by 73 to 82 $MMTCO_2e$ below 2005 levels (C2ES 2014b).

In comparison, the Proposed Action is projected to reduce CO_2 emissions by 46 to 120 $MMTCO_2e$ in the direct/indirect analysis in 2030 (depending on the alternative), with emissions levels representing a 5.7 to 16.9 percent reduction from the baseline emissions for U.S. HD vehicles in 2030.

Note that comparisons between the Proposed Action and other programs are not straightforward, given the difference in the periods over which reductions are estimated and differences in the emissions reference case. In general, the longer the period, the greater the potential emissions reductions. Table 5.4.1-3 summarizes the emissions reductions for the Proposed Action, EPA's Clean Power Plan, AB 32, and the RGGI program.

Table 5.4.1-3. Comparison of GHG Emissions Impacts between the Phase 2 HD Fuel Efficiency Improvement Program and GHG Reduction Initiatives in the United States

Program	Emissions Reduction Year	Baseline from Which Reductions are Estimated	Range of reductions ($MMTCO_2e$)
Phase 2 HD fuel efficiency standards, Direct and Indirect Analysis	2030	Business as usual baseline	46–120
Clean Power Plan under Section 111(d) of the Clean Air Act[a]	2030	Annual emissions in 2005	730
Regional GHG Initiative (RGGI)[b]	2020	Annual emissions in 2005	73–82
California Global Warming Solutions Act (AB 32)[c]	2020	Business as usual baseline	78

Notes:

[a] EPA 2014.

[b] C2ES 2014b projects emissions reductions from RGGI to be between 80 and 90 million short tons of CO_2 from 2005 levels (value in the table is converted to metric tons).

[c] CARB 2014 caps emissions under AB 32 at 431 $MMTCO_2e$ in 2020, compared with BAU emissions in 2020 of 509 $MMTCO_2e$.

$MMTCO_2e$ = million metric tons of carbon dioxide equivalent

Two features of these comparisons are important to emphasize. First, total emissions from the sources covered under the Clean Power Plan under Section 111(d) of the Clean Air Act, AB 32, and RGGI are projected to decrease compared to the beginning of the action (conforming to the programs' goals, which are to reduce overall emissions), while total emissions from the HD vehicles covered under the Proposed Action are projected to increase over the long term under most alternatives due to increases in VMT. However, each of the action alternatives would still result in large-scale reductions of total GHG emissions as compared to the No Action Alternative. Second, these projections are estimates only, and the scope of these climate programs differs from the scope of the Proposed Action in terms of geography, sector, and purpose.

In this case, the comparison of emissions reductions from the alternative fuel economy standards to emissions reductions associated with other programs is intended to benefit decisionmakers by providing relative benchmarks, rather than absolute metrics, for selecting among alternatives.

5.4.1.2 Social Cost of Carbon

Table 5.4.1-4 lists the benefits of the Proposed Action in terms of reduced monetized damages for CO_2. NHTSA derived the net present value of the benefits reported in these tables by: (1) utilizing the estimates of the SCC per ton reported previously in Section 5.3.2, (2) applying each future year's SCC estimate (per ton) to the projected reduction in CO_2 emissions during that year under each action

alternative, presented in Section 5.4.1, (3) discounting the resulting figure to its present value, and (4) summing the estimated reductions in the SCC for each year from 2018 to 2050. For internal consistency, the annual benefits are discounted to net present value terms using the same discount rate as each SCC estimate (i.e., 5 percent, 3 percent, and 2.5 percent), rather than the 3 percent and 7 percent discount rates applied to other future benefits.

Table 5.4.1-5 contains the results of a sensitivity analysis of the benefits of the Proposed Action in terms of reduced monetized damages for CH_4 and N_2O. NHTSA derived the net present value of the benefits reported in this table by using the same methodology described above. As discussed in Section 5.3.1, although the SCC estimates published in the 2010 and 2013 TSDs apply to CO_2 emissions, performing a sensitivity analysis of the benefits of reduced CH_4 and N_2O emissions has been done by others and is considered less uncertain than assuming that the social costs of non-CO_2 GHGs are zero (Marten and Newbold 2011). These estimates show increasing benefits with decreasing discount rates and with higher GHG damage estimates. The estimated net present value for a given action alternative varies by approximately an order of magnitude across the discount rates. The estimated net present value computed using a single discount rate differs by roughly a factor of three across alternatives.

Table 5.4.1-4. Reduced Monetized Damages from CO_2 Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative (net present value in 2015 in millions of 2012 dollars)[a]

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
Alt. 2	$10,515	$49,155	$78,329	$152,638
Alt. 3 – Preferred	$19,876	$93,301	$148,801	$289,873
Alt. 4	$20,998	$98,188	$156,470	$304,916
Alt. 5	$27,393	$127,928	$203,816	$397,214

Notes:
[a] Includes emissions reductions that occur between 2017 and 2050 as a result of Phase 2 HD standards.

Table 5.4.1-5. Sensitivity Analysis of Reduced Monetized Damages from CH4 and N2O Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative[a]

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
Alt. 2	$421	$1,974	$3,147	$6,132
Alt. 3 – Preferred	$709	$3,329	$5,308	$10,341
Alt. 4	$742	$3,471	$5,532	$10,779
Alt. 5	$946	$4,418	$7,039	$13,718

Notes:
[a] Net present value in 2015 in millions of 2012 dollars. Includes emissions reductions that occur between 2017 and 2050 as a result of Phase 2 HD standards.

5.4.1.3 Direct and Indirect Impacts on Climate Change Indicators

Sections 5.4.1.3.1 through 5.4.1.3.4 describe the direct and indirect impacts of the alternatives on four relevant climate change indicators: atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise. Section 5.4.1.3.5 presents the sensitivity analysis. The impacts of the Proposed Action and alternatives on global mean surface temperature, precipitation or sea-level rise are small compared to the expected changes associated with the emissions trajectories in the GCAM Reference scenario. This is due primarily to the global and multi-sectoral nature of the climate problem. Although these effects are small, they occur on a global scale and are long-lasting. The combined impact of these

emissions reductions with emissions reductions from other sources can have large health, societal, and environmental benefits.

5.4.1.3.1 Atmospheric CO_2 Concentrations

MAGICC6 is a simple climate model well calibrated to the mean of the multi-model ensemble results for four of the most commonly used emissions scenarios—RCP 2.6 (low), RCP 4.5 (medium), RCP 6.0 (medium-high), and RCP8.5 (high) from the IPCC RCP series—as shown in Table 5.4.1-6.[30] As the table shows, the results of the model runs developed for this analysis agree relatively well with IPCC estimates for both CO_2 concentrations and surface temperature.

Table 5.4.1-6. Comparison of MAGICC Modeling Results and Reported IPCC Results[a,b]

	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
Scenario	**IPCC WGI (2100)**	**MAGICC (2100)**	**IPCC WGI (2081—2100)**	**MAGICC (2100)**
RCP 2.6	421	426	1.0	1.1
RCP 4.5	538	544	1.8	2.1
RCP 6.0	670	674	2.2	2.6
RCP 8.5	936	938	3.7	4.2

Notes:
[a] Source: IPCC 2013.
[b] The IPCC values represent the average of the 5 to 95 percent range of global mean surface air temperature.

As discussed in Section 5.3.3.3.1, NHTSA used the GCAM Reference scenario to represent the No Action Alternative in the MAGICC modeling runs. CO2 concentrations range from 787.9 ppm under Alternative 5 to 789.1 ppm under the No Action Alternative in 2100. For 2040 and 2060, the corresponding range is even tighter. Because CO2 concentrations are the key determinant of other climate effects (which in turn act as drivers on the resource impacts discussed in Section 5.5.1), this leads to small differences in these effects. Even though these effects are small, they occur on a global scale and are long-lasting. As Figure 5.4.1-4 and Figure 5.4.1-5 show, the reduction in the increases in projected CO2 concentrations under each action alternative compared to the No Action Alternative amounts to a small fraction of the projected total increases in CO2 concentrations. However, the relative impact of the action alternatives is demonstrated by the reduction in increases of CO2 concentrations under the range of action alternatives. As shown in Figure 5.4.1-5, the reduction in CO2 concentrations by 2100 under Alternative 5 is more than twice that of Alternative 2.

5.4.1.3.2 Temperature

MAGICC simulations of mean global surface air temperature increases. Under the No Action Alternative in all analyses, global surface air temperature is projected to increase from 1986–2005 average levels by 1.29°C (2.32°F) by 2040, 2.01°C (3.61°F) by 2060, and 3.48°C (6.27°F) by 2100.[31]

[30] NHTSA used the MAGICC default climate sensitivity of 3.0 °C (5.4 °F).

[31] Because the actual increase in global mean surface temperature lags the commitment to warming, the impact on global mean surface temperature increase is less than the impact on the long-term commitment to warming. The actual increase in surface temperature lags the commitment due primarily to the time required to heat the ocean to the level committed by the concentrations of the GHGs.

Table 5.4.1-7 and Figure 5.4.1-4 through Figure 5.4.1-7 present the results of MAGICC simulations for the No Action Alternative and the three action alternatives in terms of CO_2 concentrations and increases in global mean surface temperature in 2040, 2060, and 2100. CO_2 concentrations range from 787.9 ppm under Alternative 5 to 789.1 ppm under the No Action Alternative in 2100. For 2040 and 2060, the corresponding range is even tighter. Because CO_2 concentrations are the key determinant of other climate effects (which in turn act as drivers on the resource impacts discussed in Section 5.5.1), this leads to small differences in these effects. Even though these effects are small, they occur on a global scale and are long-lasting. As Figure 5.4.1-4 and Figure 5.4.1-5 show, the reduction in the increases in projected CO_2 concentrations under each action alternative compared to the No Action Alternative amounts to a small fraction of the projected total increases in CO_2 concentrations. However, the relative impact of the action alternatives is demonstrated by the reduction in increases of CO_2 concentrations under the range of action alternatives. As shown in Figure 5.4.1-5, the reduction in CO_2 concentrations by 2100 under Alternative 5 is more than twice that of Alternative 2.

Table 5.4.1-7. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise (GCAM Reference) by Alternative[a]

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-level rise (cm)[b]		
Totals by Alternative	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**
Alt. 1 – No Action	479.0	565.4	789.1	1.287	2.008	3.484	22.87	36.56	76.28
Alt. 2	479.0	565.2	788.6	1.287	2.008	3.483	22.87	36.56	76.25
Alt. 3 – Preferred	478.9	565.0	788.2	1.287	2.007	3.481	22.87	36.55	76.22
Alt. 4	478.9	565.0	788.2	1.287	2.007	3.481	22.87	36.55	76.22
Alt. 5	478.8	564.9	787.9	1.286	2.006	3.480	22.87	36.54	76.20
Reductions Under Alternatives									
Alt. 2	0.1	0.2	0.5	0.000	0.001	0.002	0.00	0.00	0.03
Alt. 3 – Preferred	0.1	0.4	0.9	0.000	0.001	0.003	0.00	0.01	0.06
Alt. 4	0.1	0.4	0.9	0.000	0.002	0.003	0.00	0.01	0.06
Alt. 5	0.2	0.5	1.2	0.001	0.002	0.004	0.00	0.02	0.09

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986-2005.

Figure 5.4.1-4. Atmospheric CO_2 Concentrations by Alternative

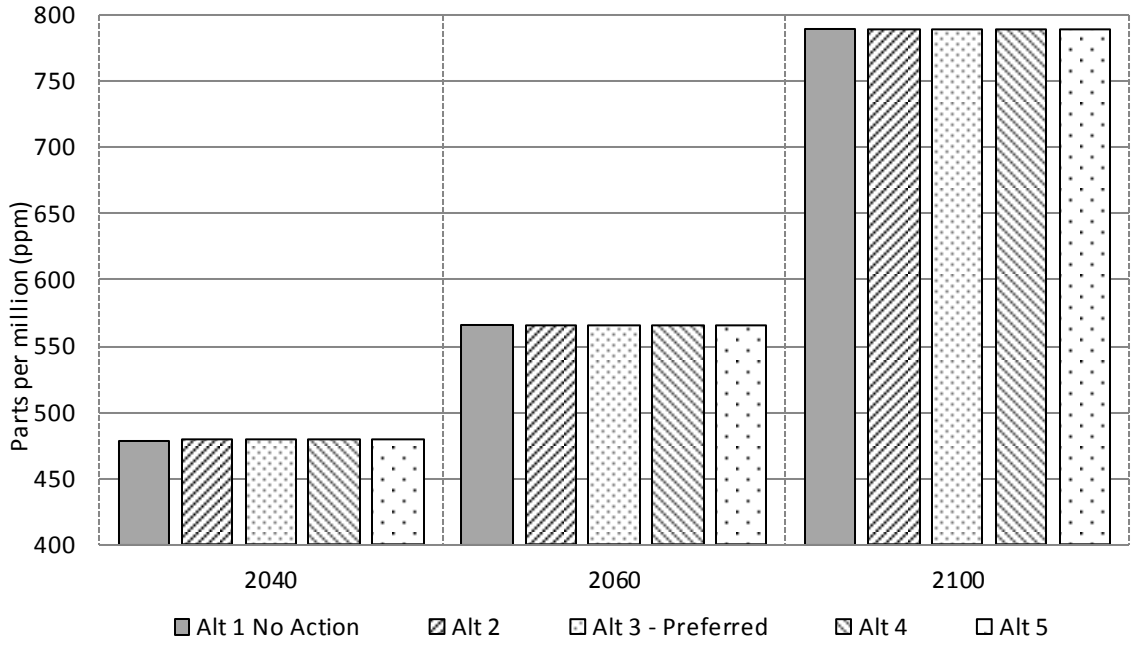


Figure 5.4.1-5. Reduction in Atmospheric CO2 Concentrations Compared to the No Action Alternative

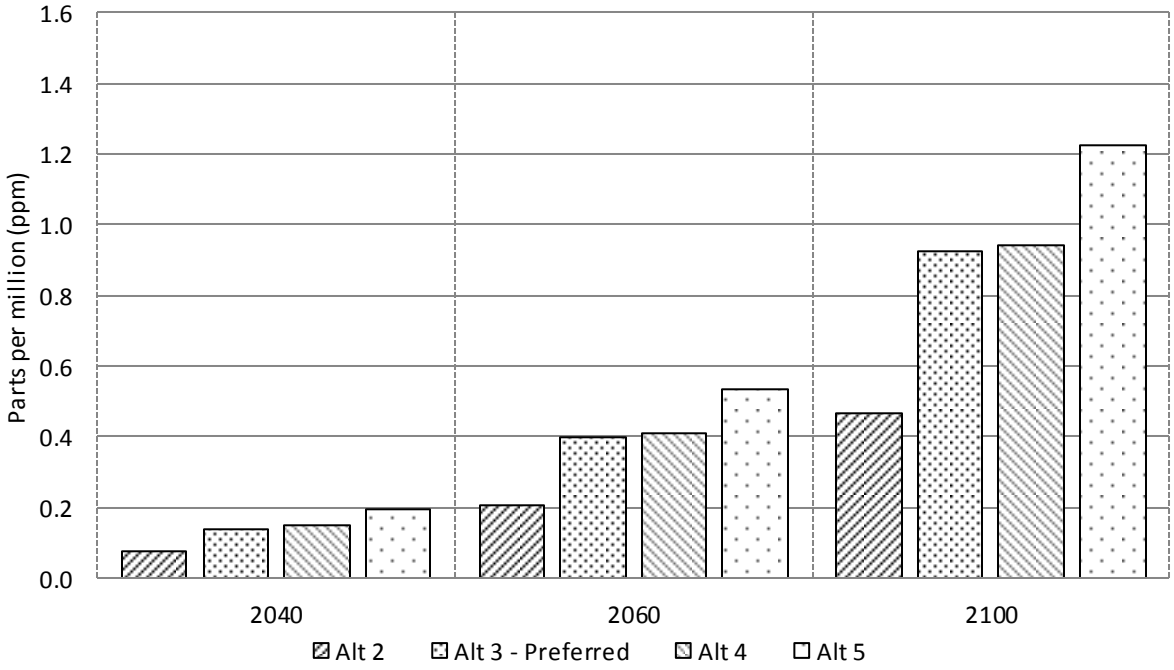


Figure 5.4.1-6. Global Mean Surface Temperature Increase by Alternative

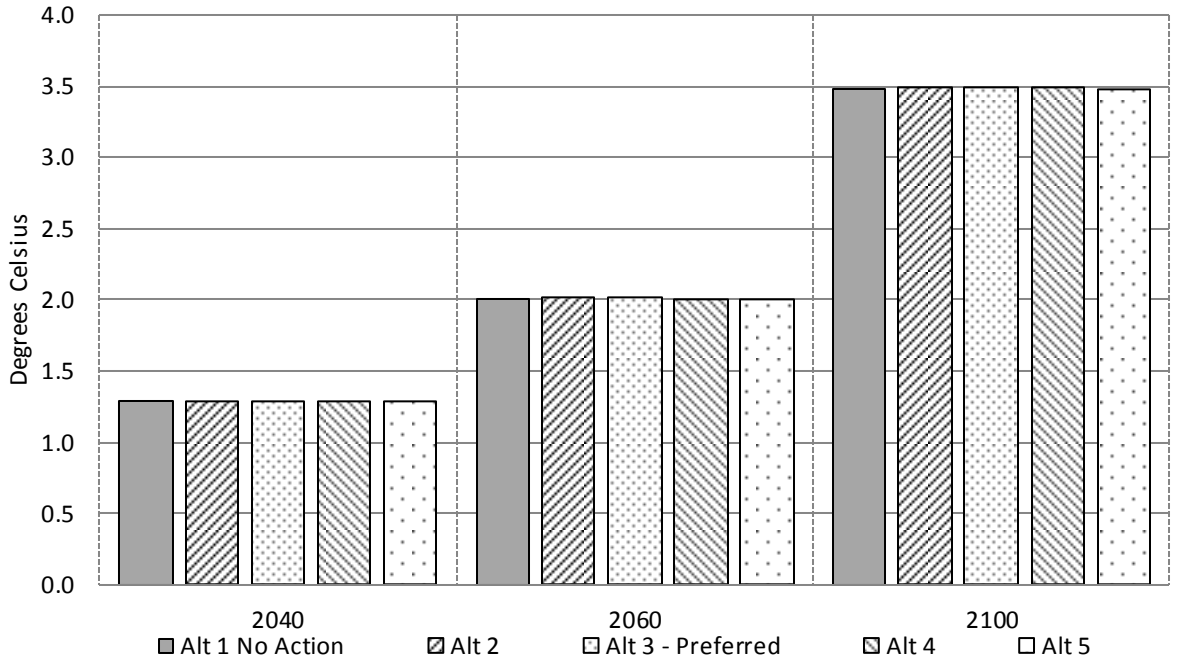
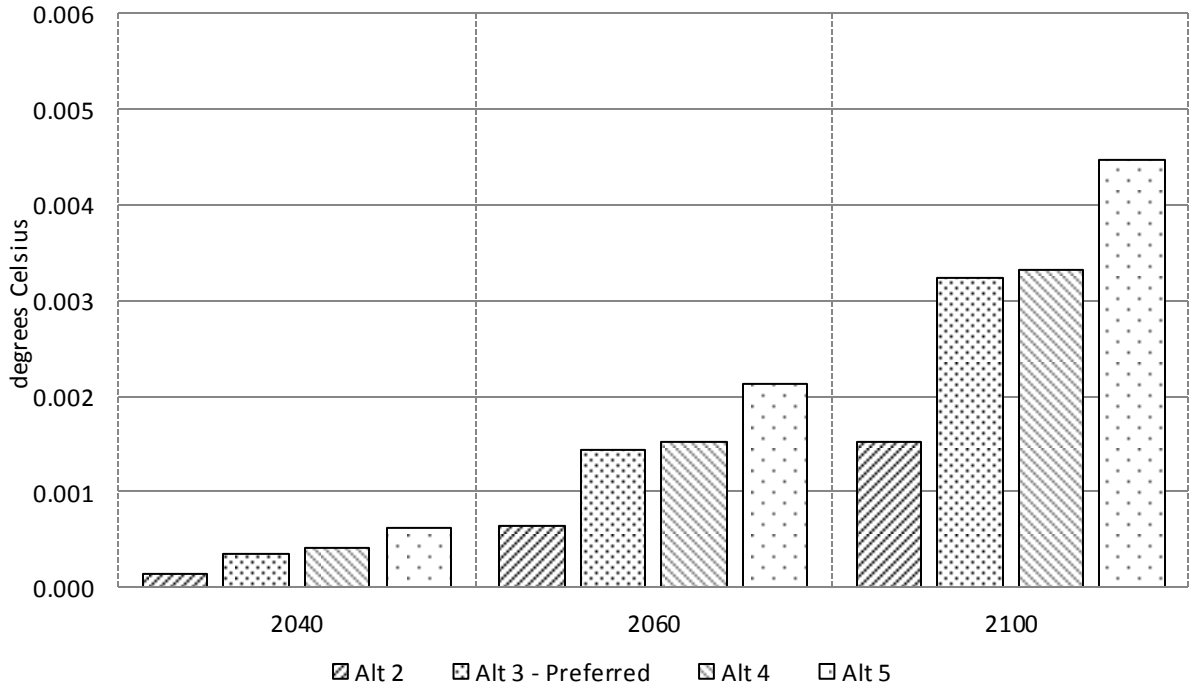


Figure 5.4.1-7. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative



The differences among the reductions in baseline temperature increases projected to result from the various action alternatives are small compared to total projected changes. For example, in 2100 the

reduction in temperature increase compared to the No Action Alternative ranges from 0.002°C (0.003°F) under Alternative 2 to 0.004°C (0.008°F) under Alternative 5. Figure 5.4.1-7 also illustrates that reductions in the growth of projected global mean surface temperature under each action alternative compared to the No Action Alternative are anticipated to be small compared to total projected changes. However, the relative impacts of the action alternatives compared to one another can be seen by comparing the reductions in the increases in global mean surface temperature projected to occur under Alternatives 2 and 5. As shown in Figure 5.4.1-7, the reduction in the projected growth in global temperature under Alternative 5 is more than twice as large as that under Alternative 2.

Table 5.4.1-8 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC Fifth Assessment Report (AR5). At this time, quantifying the changes in regional climate as a result of the action alternatives is not possible due to the limitations of existing climate models, but the action alternatives would be expected to reduce the regional impacts in proportion to reductions in global mean surface temperature.

Table 5.4.1-8. Regional Changes to Warming and Seasonal Temperatures Summarized from the IPCC Fifth Assessment Report

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Africa	Northern Africa and Northern Sahara	*Very likely* increase in mean annual temperature[a,b] *Likely* increase throughout region to be higher than global mean annual warming[e]	*Likely* greater warming at night compared to day resulting in a reduction in future temperature rise[e]
	East Africa	*Very likely* increase in mean annual temperature[a,b]	
	Southern Africa	*Very likely* increase in mean annual temperature[a,b] *Likely* higher mean land surface warming than global average	
	Western Africa	*Very likely* increase in mean annual temperature[a,b]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, and increase in more frequent droughts
Mediterranean and Europe	Northern Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in winter temperature than in Central or Southern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves (though little change over Scandinavia)
	Central Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
	Southern Europe and Mediterranean	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
Asia	Central Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	Northern Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Eastern Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	West Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	South Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeast Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
North America	Northern regions/Northern North America	*Very likely* increase in mean annual temperature[a,b]	Minimum winter temperatures are *likely* to increase more than the average
	Southwest	*Very likely* increase in mean annual temperature[a,b]	
Central and South America	Central America and the Caribbean	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeastern South America	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Amazon Region	*Very likely* increase in temperatures, greater than in other Central and South American locations	*Likely* increase in hot days and decrease in cool days, *very likely* increase in warm nights and decrease cold nights, *likely* increase in frequency and duration of heat waves
	Andes Region	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northeastern Brazil	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
Australia and New Zealand	Southern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	Southwestern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Rest of Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	New Zealand	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
Polar Regions	Arctic	*Likely* that surface temperatures will be strongly influenced by anthropogenic forcing by mid-century	
	Antarctic	*Very likely* to increase lower than global mean	
Small Islands		*Very likely* increase in temperature	

Note: Information is omitted from the table where no data was available from AR5.

Regional changes are provided for end-of-century compared to today's baseline, unless otherwise noted. Future modeled change can vary depending on a number of factors such as the concentration pathways used to drive the climate models (e.g., the amount of CO_2 emitted each year around the globe). The following superscripts were used to distinguish the various concentration pathways associated with specific findings:

[a.] RCP2.6

[b.] RCP8.5

[c.] RCP4.5

[d.] RCP6.0

[e.] SRES A1B

No superscripts were used for those findings where the concentration pathways were not identified.

Source: IPCC 2013.

5.4.1.3.3 Precipitation

In some areas, the increase in energy available to the hydrologic cycle might increase precipitation. Increases in precipitation result from higher temperatures causing more water evaporation, which causes more water vapor to be available for precipitation (EPA 2009e). Increased evaporation leads to increased precipitation in areas where surface water is sufficient, such as over oceans and lakes. In drier areas, increased evaporation can actually accelerate surface drying, which can lead to droughts (EPA 2009e). Overall, according to the IPCC (IPCC 2013), global mean precipitation is expected to increase under all climate scenarios. However, spatial and seasonal variations will be considerable. Generally, precipitation increases are very likely to occur in high latitudes, and decreases are likely to occur in the sub-tropics (EPA 2009e).

MAGICC does not directly simulate changes in precipitation, and NHTSA has not undertaken precipitation modeling with a full Atmospheric-Ocean General Circulation Model. However, the IPCC (IPCC 2013) summary of precipitation represents the most thoroughly reviewed, credible means of producing an assessment of this highly uncertain factor. NHTSA expects that the Proposed Action and

alternatives would reduce anticipated changes in precipitation (i.e., in a reference case with no GHG emissions reduction policies) in proportion to the effects of the alternatives on temperature.

The global mean change in precipitation provided by the IPCC for the RCP8.5 (high), RCP6.0 (medium-high), RCP4.5 (medium) and RCP2.6 (low) scenarios (IPCC 2013) is given as the scaled change in precipitation (expressed as a percentage change from 1980 to 1999 averages) divided by the increase in global mean surface warming for the same period (per °C), as shown in Table 5.4.1-9. The IPCC provides average scaling factors in the year range of 2006 to 2100. NHTSA used the scaling factors for the RCP6.0 scenario (which has a radiative forcing in 2100 of 6 W/m^2, similar to the GCAM Reference scenario's radiative forcing of 7 W/m^2) in this analysis because MAGICC does not directly estimate changes in global mean precipitation.

Applying these scaling factors to the reductions in global mean surface warming provides estimates of changes in global mean precipitation. The action alternatives are projected to reduce temperature increases and predicted increases in precipitation slightly compared to the No Action Alternative, as shown in Table 5.4.1-10 (based on the scaling factor from the RCP6.0 scenario).

Table 5.4.1-9. Rates of Global Mean Precipitation Increase over the 21st Century, per Emissions Scenario

Scenario	Percent per °C
RCP8.5	1.58
RCP6.0	1.68
RCP4.5	1.96
RCP2.6	2.39

Notes:
Source: Reto, Knutti 2014.

Table 5.4.1-10. Global Mean Precipitation (percent Increase) Based on GCAM Reference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative[a]

Scenario	2040	2060	2100
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.68		
Global Temperature Above Average 1986–2005 Levels (°C) for the GCAM Reference Scenario by Alternative			
Alt. 1 - No Action	1.287	2.008	3.484
Alt. 2	1.287	2.008	3.483
Alt. 3 – Preferred	1.287	2.007	3.481
Alt. 4	1.287	2.007	3.481
Alt. 5	1.286	2.006	3.480
Reduction in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative)[b]			
Alt. 2	0.000	0.001	0.002
Alt. 3 – Preferred	0.000	0.001	0.003
Alt. 4	0.000	0.002	0.003
Alt. 5	0.001	0.002	0.004
Global Mean Precipitation Increase by Alternative (%)			
Alt. 1 - No Action	2.16%	3.37%	5.85%
Alt. 2	2.16%	3.37%	5.85%
Alt. 3 – Preferred	2.16%	3.37%	5.85%
Alt. 4	2.16%	3.37%	5.85%

Scenario	2040	2060	2100
Alt. 5	2.16%	3.37%	5.85%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alt. 2	0.00%	0.00%	0.00%
Alt. 3 – Preferred	0.00%	0.00%	0.01%
Alt. 4	0.00%	0.00%	0.01%
Alt. 5	0.00%	0.00%	0.01%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.

In addition to changes in mean annual precipitation, climate change is anticipated to affect the intensity of precipitation.[32] Regional variations and changes in the intensity of precipitation cannot be further quantified, primarily due to the lack of available AOGCMs required to estimate these changes. These models typically are used to provide results among scenarios with very large changes in emissions, such as the RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high) and RCP8.5 (high) scenarios; very small changes in emissions profiles (such as those resulting from the action alternatives considered here) would produce results that would be difficult to resolve among scenarios. Also, the multiple AOGCMs produce results regionally consistent in some cases but inconsistent in others.

Table 5.4.1-11 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC Fifth Assessment Report. Quantifying the changes in regional climate under the action alternatives is not possible at this time, but the action alternatives would be expected to reduce the relative precipitation changes in proportion to the reduction in global mean surface temperature.

Table 5.4.1-11. Regional Changes to Precipitation Summarized from the IPCC Fifth Assessment Report

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
Africa	Northern Africa and Northern Sahara	*Very Likely* to decreases in mean annual precipitation[b]	
	Eastern Africa	*Likely* increases in mean annual precipitation beginning mid-century[b] *Likely* to increase during short rainy season *Likely* increase in heavy precipitation	
	Central Africa	*Likely* increases in mean annual precipitation beginning mid-century[b]	
	Southern Africa	*Very likely* decreases in mean annual precipitation[b]	

[32] As described in Meehl et al. 2007, the "intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but periods between rainfall events would be longer. The mid-continental areas tend to dry during summer, indicating a greater risk of droughts in those regions.

Precipitation extremes increase more than the mean in most tropical and mid- and high-latitude areas."

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
	Western Africa		
Mediterranean and Europe	Northern Europe		*Likely* to decrease
	Central Europe		
	Southern Europe and Mediterranean	*Likely* decrease in summer precipitation	
Asia	Central Asia	*Very likely* increase in annual precipitation by mid-century[a]	
	Northern Asia	*Very likely* increase in annual precipitation by mid-century[a]	
	Eastern Asia	Precipitation in boreal summer and winter is *likely* to increase. *Very likely* to be an increase in the frequency of intense precipitation. Extreme rainfall and winds associated with tropical cyclones are *likely* to increase	
	West Asia		
	South Asia	*Very likely* increase in annual precipitation by end of century[a]	
	Southeast Asia	*Very likely* increase in annual precipitation by end of century[a]	
North America	Northern regions/Northern North America	*Very likely* increase in precipitation by mid- century[a]	Snow season length and snow depth are *very likely* to decrease
	Southwest		Snow season length and snow depth are *very likely* to decrease
	Northeast USA		Snow season length and snow depth are *very likely* to decrease
	Southern Canada		
	Canada	*Very likely* increase in precipitation by mid- century[a]	Snow season length and snow depth are *very likely* to decrease
	Northernmost part of Canada	*Very likely* increase in precipitation by mid- century[a]	Snow season length and snow depth are *likely* to increase
Central and South America	Central America and the Caribbean		
	Southeastern South America	*Very likely* that precipitation will increase	
	Amazon Region	*Very likely* that precipitation will decrease in the eastern Amazon during the dry season	
	Andes and Western South America	*Very likely* that precipitation will decrease in the Central Chile and the Northern part of this region	
	Northeastern Brazil	*Very likely* that precipitation will decrease during the dry season	
Australia and New Zealand	Southern Australia		
	Southwestern Australia		
	New Zealand	*Likely* to increase in the western regions during winter and spring	

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
Polar Regions	Arctic	*Likely* increase in precipitation	
	Antarctic	*Likely* increase in precipitation	
Small Islands		Rainfall *likely* to increase over certain regions	

Note: Information is omitted from the table where no data was available from AR5.

Regional changes are provided for end-of-century compared to today's baseline, unless otherwise noted. Future modeled change can vary depending on a number of factors such as the concentration pathways used to drive the climate models (e.g., the amount of CO_2 emitted each year around the globe). The following superscripts were used to distinguish the various concentration pathways associated with specific findings:

[a.] RCP2.6
[b.] RCP8.5
[c.] RCP4.5
[d.] RCP6.0
[e.] SRES A1B

Source: IPCC 2013.

5.4.1.3.4 Sea-Level Rise

IPCC identifies five primary components of sea-level rise: (1) thermal expansion of ocean water, (2) melting of glaciers and ice caps, (3) loss of land-based ice in Antarctica, (4) loss of land-based ice in Greenland, and (5) contributions from anthropogenic impacts on land water storage (e.g., extraction of ground water) (IPCC 2013). Ocean circulation, changes in atmospheric pressure, and geological processes can also influence sea-level rise at a regional scale (EPA 2009). The Working Group 1 contribution to the IPCC Fifth Assessment Report (AR5) (IPCC 2013) projects the mean sea-level rise for each of the RCP scenarios. As noted in Section 5.3.3.2, NHTSA has used the relationship between the sea-level rise and temperature increases for each of the scenarios from IPCC AR5 to project sea-level rise in this EIS.

IPCC AR5 projects ranges of sea-level rise for each of the RCP scenarios. For 2081 to 2100, sea-level rise is likely to increase 26 to 55 centimeters (10.2 to 21.7 inches) for RCP2.6, 32 to 63 centimeters (12.6 to 24.8 inches) for RCP4.5, 33 to 63 centimeters (13.0 to 24.8 inches) for RCP6.0, and 45 to 82 centimeters (17.7 to 32.3 inches) for RCP8.5 compared to 1986–2005 (IPCC 2013b). Sea-level rise projections in AR5 are substantially higher than those in the Fourth Assessment Report (AR4) because they include significant contributions of melting from large ice sheets (in particular, Greenland and Antarctica) and mountain glaciers in AR5 compared to AR4. Further, the contribution from anthropogenic impacts on land water, which were not included in AR4, also adds to the overall increase in projected sea-level rise (IPCC 2013). However, IPCC results for sea-level projections are still lower than those modeled by some other studies, which were based largely on semi-empirical relationships (USACE 2014). NOAA notes that there is high confidence that the global mean sea level will rise at least 20 centimeters (8 inches) and no more than 200 centimeters (78 inches) by 2100 (Parris et al. 2012). *See* Sections 5.1.5 and 5.3.3.2 for more information on sea-level rise. CO_2 concentrations range from 787.9 ppm under Alternative 5 to 789.1 ppm under the No Action Alternative in 2100. For 2040 and 2060, the corresponding range is even tighter. Because CO_2 concentrations are the key determinant of other climate effects (which in turn act as drivers on the resource impacts discussed in Section 5.5.1), this leads to small differences in these effects. Even though these effects are small, they occur on a global scale and are long-lasting. As Figure 5.4.1-4 and Figure 5.4.1-5 show, the reduction in the increases in projected CO_2 concentrations under each action alternative compared to the No Action Alternative amounts to a small fraction of the projected total increases in CO_2 concentrations. However, the relative impact of the action alternatives is demonstrated by the reduction in increases of CO_2 concentrations under the range of action

alternatives. As shown in Figure 5.4.1-5, the reduction in CO_2 concentrations by 2100 under Alternative 5 is more than twice that of Alternative 2.

5.4.1.3.5 Temperature

MAGICC simulations of mean global surface air temperature increases. Under the No Action Alternative in all analyses, global surface air temperature is projected to increase from 1986–2005 average levels by 1.29°C (2.32°F) by 2040, 2.01°C (3.61°F) by 2060, and 3.48°C (6.27°F) by 2100.

Table 5.4.1-7 lists the impacts of the action alternatives on sea-level rise under the GCAM Reference scenario. This analysis shows sea-level rise in 2100 ranging from 76.28 centimeters (30.03 inches) under the No Action Alternative to 76.20 centimeters (30.00 inches) under Alternative 5. This represents a maximum reduction of 0.09 centimeter (0.03 inches) by 2100 under Alternative 5 compared to the No Action Alternative.

5.4.1.3.6 Climate Sensitivity Variations

Using the methodology described in Section 5.3.3.5, NHTSA examined the sensitivity of projected climate impacts on key technical or scientific assumptions used in the analysis. This examination included modeling the impact of various climate sensitivities on the climate effects under the No Action Alternative and the Preferred Alternative using the GCAM Reference scenario.

Table 5.4.1-12 lists the results from the sensitivity analysis, which included climate sensitivities of 1.5°C, 2.0°C, 2.5°C, 3.0°C, 4.5°C, and 6.0°C (2.7°F, 3.6°F, 4.5°F, 5.4°F, 8.1°F, and 10.8°F) for a doubling of CO_2 compared to pre-industrial atmospheric concentrations (280 ppm CO_2) (*see* Section 5.3.3.5).

Table 5.4.1-12. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level rise for Varying Climate Sensitivities for Selected Alternatives[a]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[b]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 – No Action	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70
Alt. 3 – Preferred	1.5	469.47	545.71	736.62	0.740	1.127	1.888	41.02
	2.0	472.95	552.70	754.60	0.941	1.445	2.449	52.70
	2.5	476.08	559.12	771.78	1.122	1.737	2.978	64.47
	3.0	478.90	565.04	788.18	1.287	2.007	3.481	76.22
	4.5	485.86	580.22	833.31	1.698	2.705	4.864	110.84
	6.0	491.20	592.46	873.83	2.019	3.277	6.165	144.57
Reduction Under Preferred Alternative Compared to No Action Alternative								
	1.5	0.14	0.39	0.86	0.000	0.001	0.002	0.03
	2.0	0.14	0.39	0.89	0.000	0.001	0.002	0.04
	2.5	0.14	0.40	0.91	0.000	0.001	0.003	0.05
	3.0	0.14	0.40	0.93	0.000	0.001	0.003	0.06
	4.5	0.14	0.40	0.97	0.000	0.002	0.004	0.09
	6.0	0.14	0.41	1.06	0.000	0.002	0.006	0.13

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986-2005.

As the tables show, varying climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from pre-industrial levels) can affect not only estimated warming, but also estimated sea-level rise and CO_2 concentration. This complex set of interactions occurs because sea level is influenced by temperature, while atmospheric CO_2 concentrations are affected by temperature-dependent effects of ocean carbon storage (specifically, higher temperatures result in lower aqueous solubility of CO_2). Therefore, as Table 5.4.1-12 shows, projected future atmospheric CO_2 concentrations differ with varying climate sensitivities even under the same alternative, despite the fact that CO_2 emissions are fixed under each alternative.

Simulated atmospheric CO_2 concentrations in 2040, 2060, and 2100 are a function of changes in climate sensitivity. The small changes in concentration are due primarily to small changes in the aqueous solubility of CO_2 in ocean water: slightly warmer air and sea surface temperatures lead to less CO_2 being dissolved in the ocean and slightly higher atmospheric concentrations.

The response of simulated global mean surface temperatures to variation in the climate sensitivity parameter varies among the years 2040, 2060, and 2100, as shown in Table 5.4.1-12. In 2040, the impact of assumed variation in climate sensitivity is low, due primarily to the limited rate at which the global mean surface temperature increases in response to increases in radiative forcing. In 2100, the

impact of variation in climate sensitivity is magnified by the larger change in emissions. The reduction in 2100 global mean surface temperature from the No Action Alternative to the Preferred Alternative ranges from 0.002°C (0.004°F) for the 1.5°C (2.7°F) climate sensitivity to 0.006°C (0.011°F) for the 6.0°C (10.8°F) climate sensitivity.

The sensitivity of the simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 5.4.1-12. Scenarios with lower climate sensitivities show generally smaller increases in sea-level rise; at the same time, sea-level rise is lower under the Preferred Alternative than under the No Action Alternative. Conversely, scenarios with higher climate sensitivities have higher projected sea-level rise; again, however, sea-level rise is lower under the Preferred Alternative than under the No Action Alternative. The range in reduction of sea-level rise under the Preferred Alternative compared to the No Action Alternative is 0.03 to 0.13 centimeter (0.011 to 0.051 inch), depending on the assumed climate sensitivity.

5.4.2 Cumulative Impacts

The cumulative impacts climate analysis is broader than the corresponding direct and indirect impacts analysis in Section 5.4.1 because this section addresses the effects of the Proposed Action together with those of other past, present, and reasonably foreseeable future actions.

5.4.2.1 Greenhouse Gas Emissions

NHTSA estimated the emissions resulting from the Proposed Action using the methodologies described in Section 5.3. GHG emissions from MY 2051–2100 HD vehicles were then scaled using GCAM assumptions regarding the projected growth of U.S. transportation fuel consumption (*see* Section 5.3.1).

Cumulative emissions reductions under each action alternative increase with the increasing stringency of the alternatives, with Alternative 2 having the smallest cumulative emissions reductions and Alternative 5 having the largest. Table 5.4.2-1 and Figure 5.4.2-1 show total CO_2 emissions and emissions reductions projected to result from new U.S. HD vehicles from 2018 to 2100 under each action alternative. Between 2018 and 2100, projections of cumulative emissions reductions due to the Proposed Action and other reasonably foreseeable future actions range from 6,500 to 15,200 $MMTCO_2$. Compared to cumulative global emissions of 4,154,831 $MMTCO_2$ over this period (projected by the GCAM6.0 scenario), the incremental impact of this rulemaking is expected to reduce global CO_2 emissions by about 0.2 to 0.4 percent from their projected levels under the No Action Alternative.

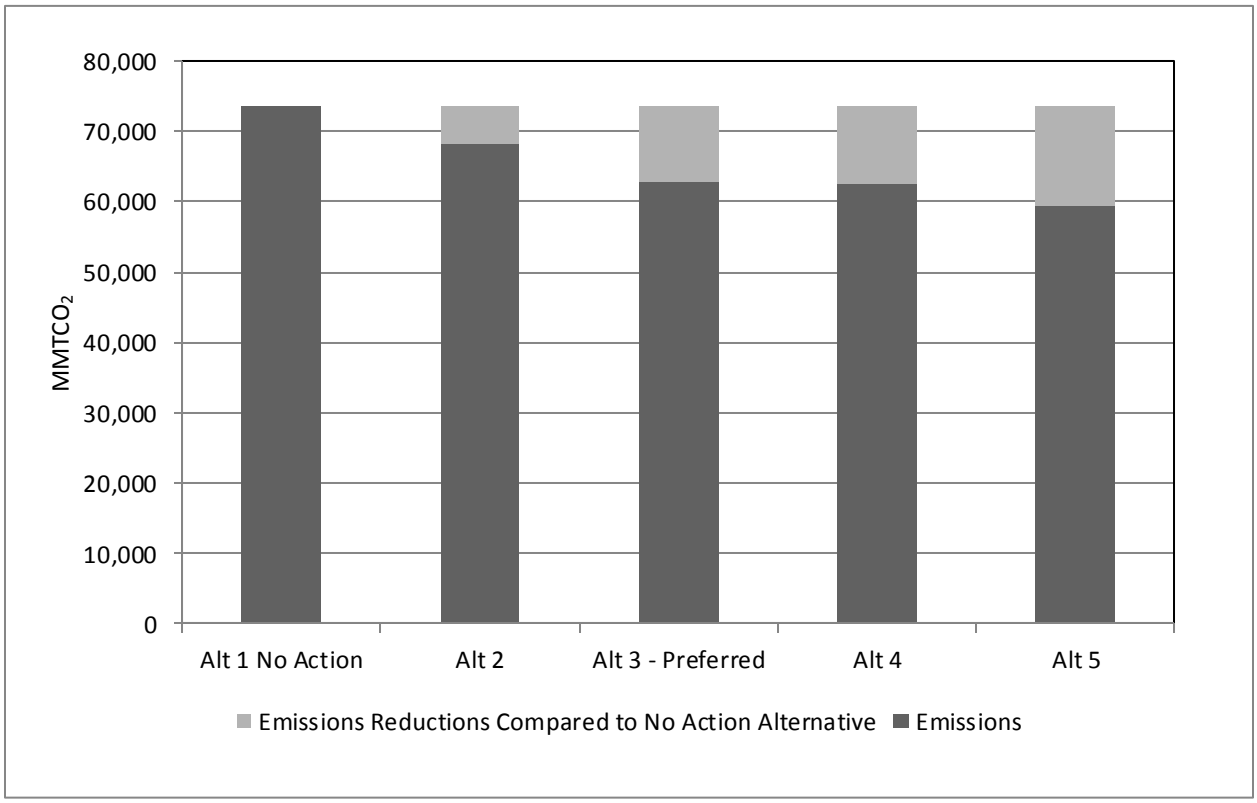
Table 5.4.2-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from all HD Vehicles 2018 to 2100 by Alternative[a]

Alternative	Total Emissions	Emissions Reductions Compared to No Action Alternative	Percent Emissions Reductions Compared to No Action Alternative Emissions
Alt. 1 – No Action	74,700		
Alt. 2	68,100	6,500	9%
Alt. 3 – Preferred	62,900	11,800	16%
Alt. 4	62,600	12,000	16%
Alt. 5	59,400	15,200	20%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

Figure 5.4.2-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles 2018 to 2100 by Alternative



To illustrate the relative impact of these reductions, it can be helpful to consider the magnitude of U.S. emissions from HD vehicles and to compare them to total U.S. emissions from all sources. HD vehicles in the United States currently account for approximately 7.5 percent of U.S. CO_2 emissions. With the action alternatives reducing U.S. HD vehicle CO_2 emissions by 9 to 20 percent over the period 2018–2100 under the cumulative impacts analysis presented in this chapter, the Proposed Action would contribute to reducing total U.S. CO_2 emissions compared to the No Action Alternative. Compared to total U.S. CO_2 emissions by the end of the century projected by the GCAM6.0 scenario of 4,402 $MMTCO_2$ (Clarke et al. 2007), the action alternatives and reasonably foreseeable future increases in HD vehicle fuel efficiency would reduce total U.S. CO_2 emissions by a range of 2.0 to 4.6 percent in the year 2100.[33] Figure 5.4.2-2 shows projected annual emissions from U.S. HD vehicles under the alternatives taken together with reasonably foreseeable future actions.

[33] 2095 is the last year emissions data are available from GCAM Reference.

Figure 5.4.2-2. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative

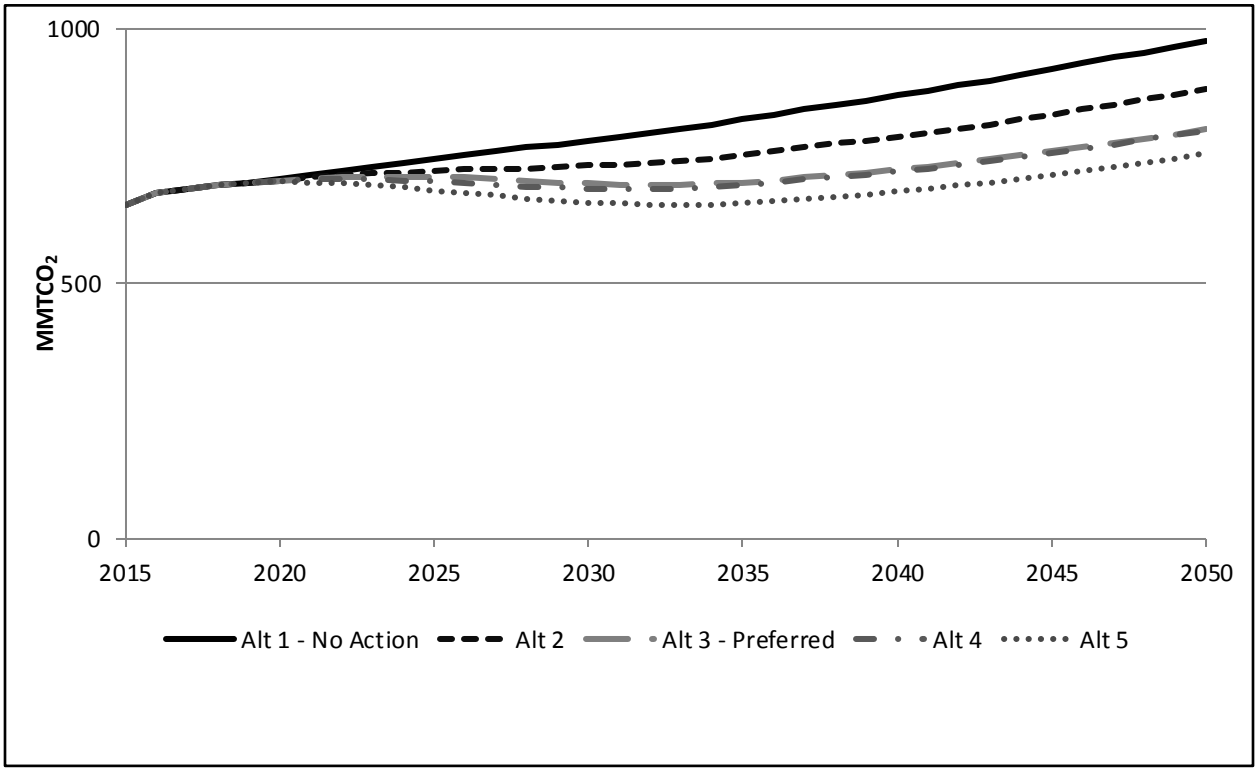


Table 5.4.2-2 shows projected emissions of CO_2, CH_4, and N_2O to 2100 under the alternatives. CO_2 emissions account for almost all—97 percent—of GWP-weighted emissions. As shown in this table, CO_2 emissions from the HD vehicle fleet in the United States are projected to increase substantially from their levels in 2018 under the No Action Alternative, which assumes increases in both the number of HD vehicles and in VMT per vehicle. This table also shows that each action alternative would reduce total HD vehicle CO_2 emissions in future years significantly from their projected levels under the No Action Alternative. Progressively larger reductions in CO_2 emissions from the levels under the No Action Alternative are projected to occur during each future year through 2050, due to decreased fuel consumption as the fleet turns over.

Table 5.4.2-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year)[a] from All HD Vehicles by Alternative

GHG and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon Dioxide (CO_2)					
2020	706	703	702	702	701
2040	869	788	723	720	680
2060	972	877	798	797	751
2080	966	871	793	791	746
2100	898	810	737	736	694
Methane (CH_4)					
2020	19.35	19.29	19.27	19.26	19.24
2040	24.17	21.18	19.34	19.26	18.07
2060	27.03	23.48	21.28	21.24	19.86
2080	26.84	23.31	21.13	21.09	19.72
2100	24.96	21.68	19.65	19.61	18.34
Nitrous oxide (N_2O)					
2020	2.13	2.13	2.13	2.12	2.12
2040	2.27	2.17	2.06	2.00	1.94
2060	2.49	2.37	2.25	2.17	2.11
2080	2.47	2.35	2.23	2.16	2.09
2100	2.30	2.19	2.08	2.01	1.95

Notes:
[a]. $MMTCO_2e$ = million metric tons carbon dioxide equivalent.

For the cumulative impacts analysis, under each alternative analyzed, growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use, is projected to result in growth of HD vehicle travel. Other than for Alternative 5, this growth in VMT more than offsets the effect of improvements in HD vehicle fuel efficiency in 2100 under all alternatives, resulting in projected increases above present levels in total fuel consumption by HD vehicles in the United States over the long term. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles. Under Alternative 5, increases in HD vehicle fuel efficiency are expected to result in fuel consumption and CO_2 emissions levels in 2100 that are lower than 2020 projected annual CO_2 emissions levels.

Emissions of CO_2 (the primary gas that drives climate effects) from the U.S. HD vehicle fleet represented approximately 1.2 percent of total global emissions of CO_2 in 2011 (EPA 2015, WRI 2015).[34] Although substantial, this source is still a small percentage of global emissions. The proportion of global CO_2 emissions attributable to HD vehicles is expected to decline in the future, due primarily to rapid growth of emissions from developing economies (which is due, in part, to growth in global transportation sector emissions).

One global climate stabilization goal that has been gaining recognition is the idea of a global carbon "budget," which is an estimate for the total amount of anthropogenic CO_2 that can be emitted to have a certain chance of limiting the global average temperature increase to below 2°C relative to pre-industrial levels. The IPCC estimates that if cumulative global emissions from 1870 onwards are limited to

[34] Includes land-use change and forestry and excludes international bunker fuels.

approximately 1,000 Gigatonnes (Gt) C (3,670 Gt CO_2), then the probability of limiting the temperature increase to below 2°C is greater than 66 percent. As of 2011, approximately 51 percent, or 515 Gt C (1,890 Gt CO_2), of this budget had already been emitted, leaving a remaining budget of 485 Gt C (1,780 Gt CO_2). (IPCC 2013)

The emissions reductions necessary to keep global emissions within this carbon budget could not be achieved solely with drastic reductions in emissions from the U.S. HD vehicle fleet but would also require drastic reductions in all U.S. sectors and from the rest of the developed and developing world. In addition, achieving GHG reductions from the HD vehicle fleet to the same degree that emissions reductions will be needed globally to avoid using all of the carbon budget would require substantial increases in technology innovation and adoption compared to today's levels and would require an economy and vehicle fleet that has largely moved away from the use of fossil fuels, which is not currently technologically feasible or economically practicable.

5.4.2.2 Social Cost of Carbon

Consistent with the methodology described in Section 5.4.1.2, Table 5.4.2-3 lists the cumulative impacts of the action alternatives in terms of reduced monetized damages, and Table 5.4.2-4 contains the results of a sensitivity analysis of the benefits of the Proposed Action in terms of reduced monetized damages for CH_4 and N_2O. Consistent with the tables in Section 5.4.1.2 (Table 5.4.1-4 and Table 5.4.1-5), these estimates show increasing benefits with decreasing discount rates (and higher damage estimates). The estimated net present value for a given alternative varies by approximately an order of magnitude across the discount rates. The estimated net present value computed using a single discount rate differs by roughly a factor of three across alternatives.

Table 5.4.2-3. Reduced Monetized Damages from CO_2 Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative[a]

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
Alt. 2	$12,689	$59,475	$94,823	$184,746
Alt. 3 - Preferred	$22,335	$104,967	$167,443	$326,163
Alt. 4	$23,497	$110,028	$175,387	$341,745
Alt. 5	$30,094	$140,711	$224,234	$436,969

Notes:
[a] Net present value in 2015, in millions of 2012 dollars. Includes emissions reductions that occur between 2017 and 2050 as a result of Phase 2 HD standards.

Table 5.4.2-4. Sensitivity Analysis of Reduced Monetized Damages from CH_4 and N_2O Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative[a]

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
Alt. 2	$464	$2,176	$3,469	$6,759
Alt. 3 - Preferred	$750	$3,522	$5,617	$10,942
Alt. 4	$789	$3,696	$5,892	$11,480
Alt. 5	$992	$4,639	$7,393	$14,407

Notes:
[a] Net present value in 2015, in millions of 2012 dollars. Includes emissions reductions that occur between 2017 and 2050 as a result of Phase 2 HD standards.

5.4.2.3 Cumulative Impacts on Climate Change Indicators

Using the methodology described in Chapter 2 and Section 5.3.3.3.2, Sections 5.4.2.3.1 through 5.4.2.3.4 describe the cumulative impacts of the alternatives on climate change in terms of atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise. Section 5.4.2.3.5 presents a sensitivity analysis of the results. The impacts of the Proposed Action, in combination with other reasonably foreseeable future actions, on global mean surface temperature, sea-level rise, and precipitation are relatively small in the context of the expected changes associated with the emissions trajectories in the GCAM scenarios.[35] Although relatively small, primarily due to the global and multi-sectoral nature of the climate problem, the impacts occur on a global scale and are long-lasting.

5.4.2.3.1 Atmospheric CO_2 Concentrations

MAGICC6 is a simple climate model and well calibrated to the mean of the multi-model ensemble results for four of the most commonly used emissions scenarios (i.e., RCP 2.6 [low], RCP 4.5 [medium], RCP 6.0 [medium-high], and RCP8.5 [high]) from the IPCC RCP series.

The GCAM6.0 scenario, described in Section 5.3.3.3, was used to represent the No Action Alternative in the MAGICC runs for the cumulative impacts section of this EIS. Table 5.4.2-5 and Figure 5.4.2-3 through Figure 5.4.2-6 show the mid-range results of MAGICC model simulations for the No Action Alternative and the four action alternatives for CO_2 concentrations and increase in global mean surface temperature in 2040, 2060, and 2100. As Figure 5.4.2-3 and Figure 5.4.2-4 show, the action alternatives produce a reduction in the increase in projected CO_2 concentration and temperature, but the reduction is a small fraction of the total increase in CO_2 concentrations and global mean surface temperature. As shown in Table 5.4.2-5 and Figure 5.4.2-3 and Figure 5.4.2-4, the band of estimated CO_2 concentrations as of 2100 is fairly narrow, from a range of 686.0 ppm under Alternative 5 to 687.3 ppm under the No Action Alternative. For 2040 and 2060, the corresponding ranges are similar. Because CO_2 concentrations are the key driver of all other climate effects, the small changes in CO_2 leads to small differences in climate effects.

5.4.2.3.2 Temperature

MAGICC simulations of mean global surface air temperature increases are shown in Table 5.4.2-5. Under the No Action Alternative, assuming an emissions scenario that considers a moderate global effort to reduce GHG emissions, the cumulative global mean surface temperature is projected to increase by 1.22°C (2.19°F) by 2040, 1.81°C (3.26°F) by 2060, and 2.84°C (5.11°F) by 2100.[36] The differences among alternatives are small. For example, in 2100 the reduction in temperature increase under the action alternatives compared to the No Action Alternative ranges from approximately 0.002°C (0.004°F) under Alternative 2 to 0.005°C (0.009°F) under Alternative 5. Quantifying the changes to regional climate from the Proposed Action is not possible at this point due to the limitations of existing climate models. However, the alternatives would be expected to reduce the changes compared to the reduction in global mean surface temperature. Regional changes to warming and seasonal temperatures as described in the IPCC Fifth Assessment Report are summarized in Table 5.4.1-8.

[35] These conclusions are not meant to express the view that impacts on global mean surface temperature, precipitation, or sea-level rise are not areas of concern for policymakers. Under NEPA, the agency is obligated to discuss "the environmental impact[s] of *the proposed action.*" 42 U.S.C. § 4332(2)(C)(i) (emphasis added).

[36] Because the actual increase in global mean surface temperature lags the commitment to warming, the impact on global mean surface temperature increase is less than the impact on the long-term commitment to warming. The actual increase in surface temperature lags the commitment due primarily to the time required to heat the oceans.

Table 5.4.2-5. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-level rise by Alternative[a]

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-Level Rise (cm)[b]		
Alternative	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**
Alt. 1 – No Action	472.6	546.0	687.3	1.216	1.810	2.838	22.16	35.15	70.22
Alt. 2	472.5	545.8	686.8	1.215	1.810	2.836	22.16	35.15	70.18
Alt. 3 – Preferred	472.4	545.6	686.3	1.215	1.809	2.834	22.16	35.14	70.15
Alt. 4	472.4	545.6	686.3	1.215	1.809	2.834	22.16	35.14	70.15
Alt. 5	472.4	545.4	686.0	1.215	1.808	2.833	22.16	35.13	70.12
Reductions Under Alternatives									
Alt. 2	0.1	0.2	0.5	0.000	0.001	0.002	0.00	0.01	0.04
Alt. 3 – Preferred	0.1	0.4	1.0	0.000	0.002	0.004	0.00	0.01	0.07
Alt. 4	0.2	0.4	1.0	0.000	0.002	0.004	0.00	0.01	0.08
Alt. 5	0.2	0.6	1.3	0.001	0.002	0.005	0.00	0.02	0.10

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

Figure 5.4.2-3. Atmospheric CO_2 Concentrations by Alternative

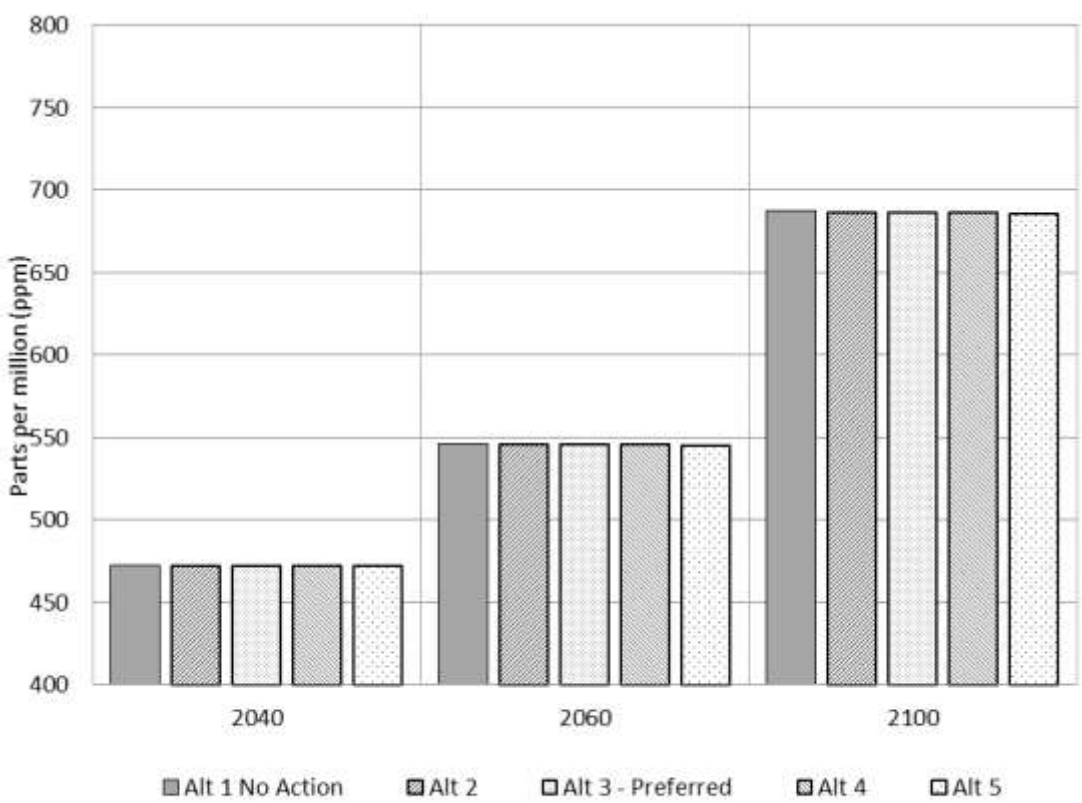


Figure 5.4.2-4. Reduction in Atmospheric CO_2 Concentrations Compared to the No Action Alternative

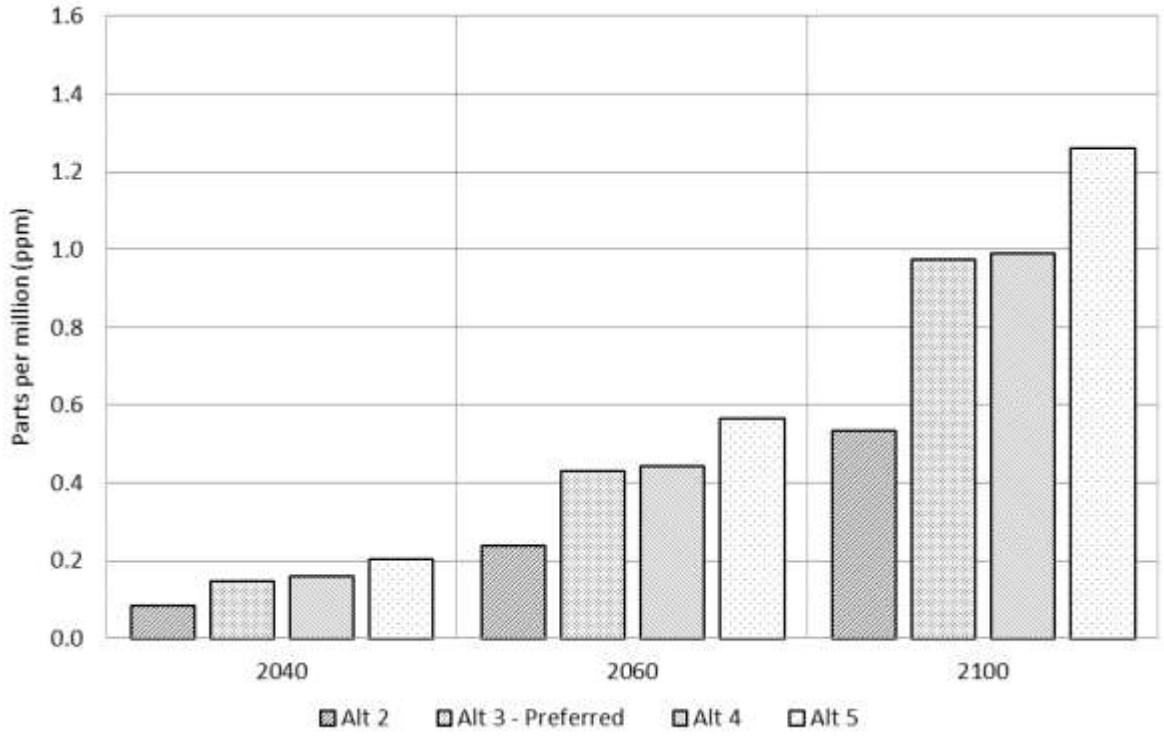


Figure 5.4.2-5. Global Mean Surface Temperature Increase by Alternative

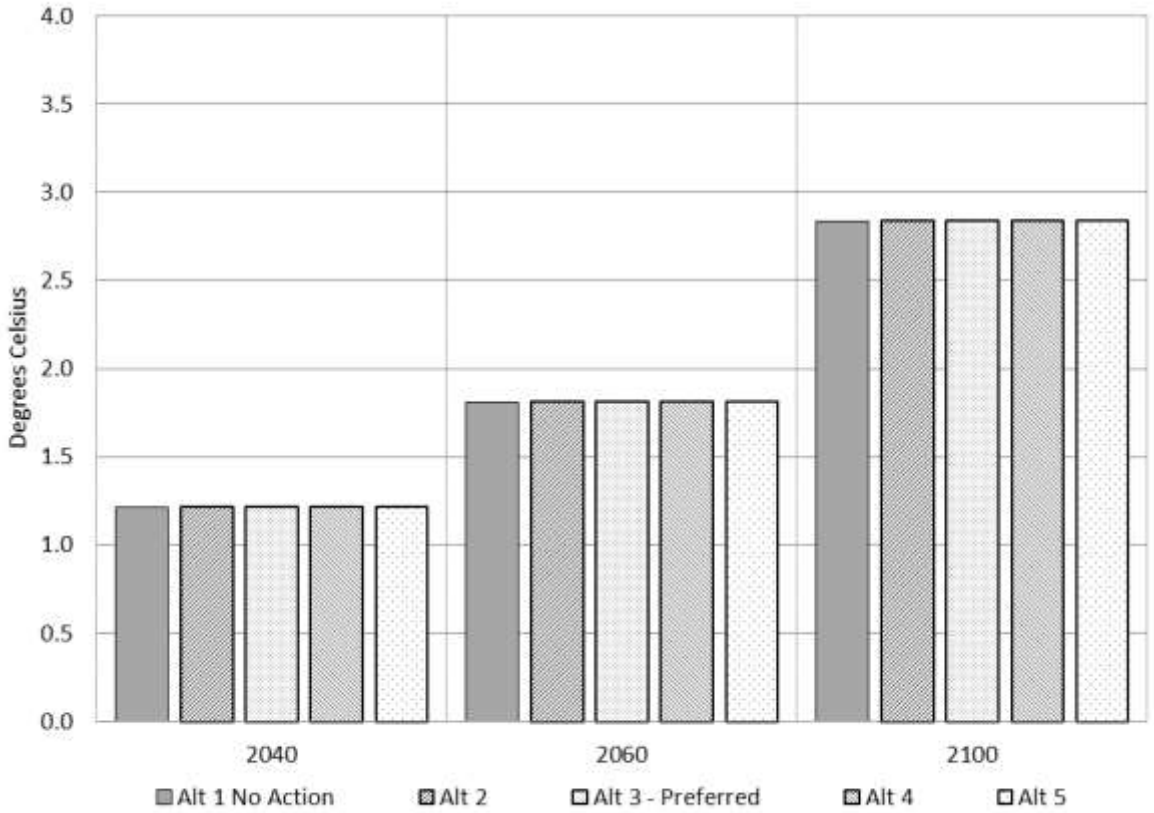
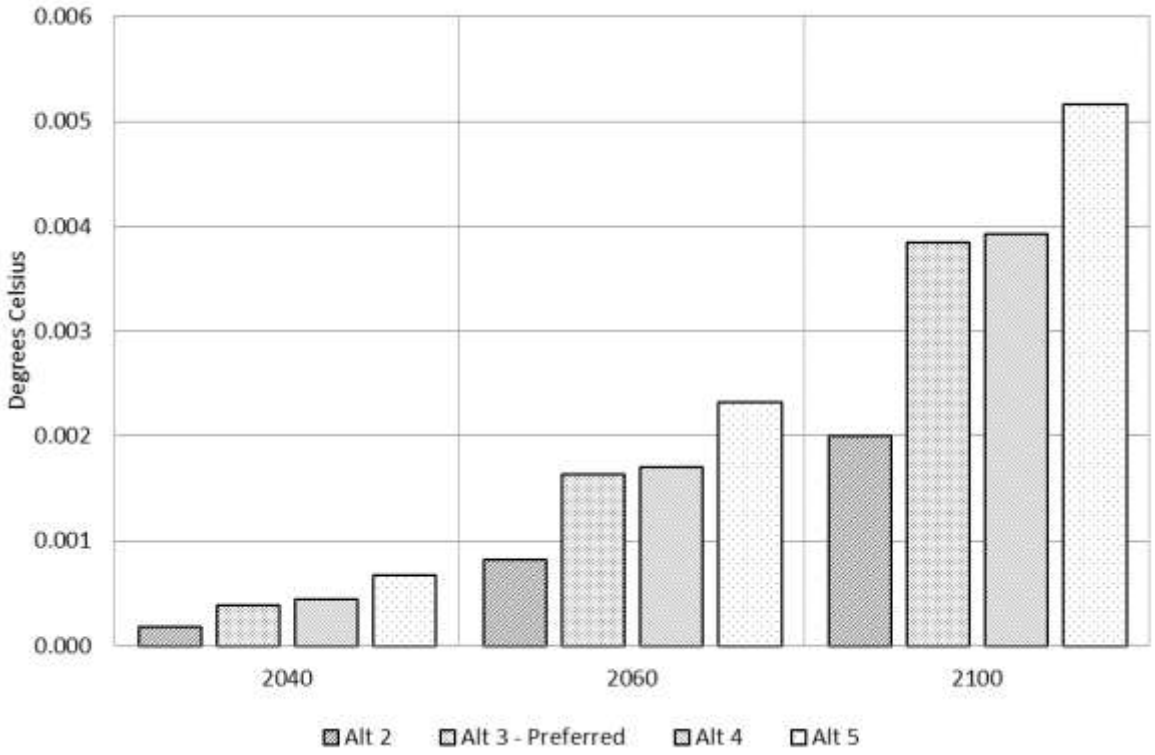


Figure 5.4.2-6. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative



5.4.2.3.3 Precipitation

The effects of higher temperatures on the amount of precipitation and the intensity of precipitation events, as well as the IPCC scaling factors to estimate global mean precipitation change, are discussed in Section 5.4.1.3.3. Applying these scaling factors to the reductions in global mean surface warming provides estimates of changes in global mean precipitation. Given that the action alternatives would reduce temperature increases slightly compared to the No Action Alternative, they also would reduce predicted increases in precipitation slightly, as shown in Regional variations and changes in the intensity of precipitation events cannot be quantified further. This inability is due primarily to the lack of availability of atmospheric-ocean general circulation models (AOGCMs) required to estimate these changes. AOGCMs are typically used to provide results among scenarios with very large changes in emissions, such as the RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high) and RCP8.5 (high) scenarios; very small changes in emissions profiles produce results that would be difficult to resolve. Also, the various AOGCMs produce results that are regionally consistent in some cases but inconsistent in others.

Regional variations and changes in the intensity of precipitation events cannot be quantified further. This inability is due primarily to the lack of availability of atmospheric-ocean general circulation models (AOGCMs) required to estimate these changes. AOGCMs are typically used to provide results among scenarios with very large changes in emissions, such as the RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high) and RCP8.5 (high) scenarios; very small changes in emissions profiles produce results that would be difficult to resolve. Also, the various AOGCMs produce results that are regionally consistent in some cases but inconsistent in others (Table 5.4.2-6).

Table 5.4.2-6. Global Mean Precipitation (percent Increase) Based on GCAM6.0 Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative[a]

Scenario	2040	2060	2100
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.68		
Global Temperature Above Average 1986–2005 Levels (°C) for the GCAM6.0 Scenario by Alternative			
Alt. 1 - No Action	1.216	1.810	2.838
Alt. 2	1.215	1.810	2.836
Alt. 3 – Preferred	1.215	1.809	2.834
Alt. 4	1.215	1.809	2.834
Alt. 5	1.215	1.808	2.833
Reduction in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative)[b]			
Alt. 2	0.000	0.001	0.002
Alt. 3 – Preferred	0.000	0.002	0.004
Alt. 4	0.000	0.002	0.004
Alt. 5	0.001	0.002	0.005
Global Mean Precipitation Increase by Alternative (%)			
Alt. 1 - No Action	2.04%	3.04%	4.77%
Alt. 2	2.04%	3.04%	4.76%
Alt. 3 - Preferred	2.04%	3.04%	4.76%
Alt. 4	2.04%	3.04%	4.76%
Alt. 5	2.04%	3.04%	4.76%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alt. 2	0.00%	0.00%	0.00%
Alt. 3 – Preferred	0.00%	0.00%	0.01%
Alt. 4	0.00%	0.00%	0.01%
Alt. 5	0.00%	0.00%	0.01%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.

Quantifying the changes in regional climate from the action alternatives is not possible at this point, but the action alternatives would reduce the changes compared to the reduction in global mean surface temperature. Regional changes to precipitation as described by the IPCC Fourth Assessment Report are summarized in Table 5.4.1-11 in Section 5.4.1.3.3.

5.4.2.3.4 Sea-Level Rise

The components of sea-level rise, treatment of these components, and recent scientific assessments are discussed in Section 5.4.1.3.4. Table 5.4.2-5 presents the cumulative impact on sea-level rise from the scenarios and show sea-level rise in 2100 ranging from 70.22 centimeters (27.65 inches) under the No Action Alternative to 70.12 centimeters (27.61 inches) under Alternative 5, for a maximum reduction of 0.10 centimeter (0.04 inch) by 2100.

5.4.2.3.5 Climate Sensitivity Variations

NHTSA examined the sensitivity of climate impacts on key assumptions used in the analysis. This examination reviewed the impact of various climate sensitivities and global emissions scenarios on the climate effects under the No Action Alternative and the Preferred Alternative. NHTSA performed the sensitivity analysis around two of the alternatives – the No Action Alternative and the Preferred Alternative – because the agency believes this is sufficient to assess the effect of various climate sensitivities on the results. Table 5.4.2-7 presents the results of the sensitivity analysis for cumulative impacts.

Table 5.4.2-7. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level rise for RCP 4.5[a] for Selected Alternatives[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 – No Action	1.5	454.05	494.89	510.15	0.619	0.859	1.040	31.58
	2.0	457.30	500.90	521.85	0.793	1.114	1.389	40.80
	2.5	460.23	506.45	533.11	0.952	1.352	1.729	50.33
	3.0	462.88	511.57	543.93	1.097	1.573	2.059	60.04
	4.5	469.44	524.72	573.71	1.464	2.152	2.978	89.27
	6.0	474.49	535.31	599.95	1.752	2.627	3.797	117.62
Alt. 3 – Preferred	1.5	453.90	494.47	509.33	0.618	0.858	1.037	31.54
	2.0	457.15	500.49	521.00	0.792	1.112	1.385	40.75
	2.5	460.09	506.03	532.24	0.951	1.350	1.725	50.27
	3.0	462.74	511.15	543.04	1.097	1.571	2.055	59.96
	4.5	469.30	524.29	572.77	1.463	2.149	2.972	89.14
	6.0	474.34	534.87	598.96	1.751	2.624	3.790	117.46
Reduction Under Preferred Alternative Compared to the No Action Alternative								
	1.5	0.15	0.41	0.83	0.000	0.001	0.003	0.04
	2.0	0.15	0.42	0.85	0.000	0.001	0.003	0.05
	2.5	0.15	0.42	0.87	0.000	0.002	0.004	0.06
	3.0	0.15	0.42	0.89	0.000	0.002	0.004	0.08
	4.5	0.15	0.43	0.95	0.000	0.002	0.006	0.12
	6.0	0.15	0.43	0.99	0.000	0.002	0.007	0.16

Notes:

[a] Sea-level rise results are based on the regression analysis described in Section 5.3.3.

[b] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[c] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

The use of alternative global emissions scenarios can influence the results in several ways. Emissions reductions can lead to larger reductions in CO_2 concentrations in later years because more of the anthropogenic emissions are expected to stay in the atmosphere. The use of different climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from pre-industrial levels) could affect not only warming but also indirectly affect sea-level rise and CO_2 concentration. Sea level is influenced by temperature. CO_2 concentration is affected by temperature-dependent effects of ocean carbon storage (higher temperature results in lower aqueous solubility of CO_2).

As shown in Table 5.4.2-7 through Table 5.4.2-9, the sensitivity of simulated CO_2 emissions in 2040, 2060, and 2100 to assumptions of global emissions and climate sensitivity is low; stated simply, the incremental changes in CO_2 concentration (i.e., the delta between the Preferred Alternative and the No Action Alternative) are insensitive to different assumptions on global emissions and climate sensitivity. For 2040 and 2060, the choice of global emissions scenario has little impact on the results. By 2100, the Preferred Alternative has the greatest impact on CO_2 concentration in the global emissions scenario with the highest CO_2 emissions (GCAM Reference scenario) and the least impact in the scenario with the lowest CO_2 emissions (RCP4.5). The total range of the impact of the Preferred Alternative on CO_2 concentrations in 2100 is roughly 0.83 to 1.16 ppm. The Preferred Alternative using the GCAM6.0 scenario and a 3.0°C (5.4°F) climate sensitivity has an impact of a 0.97 ppm reduction compared to the No Action Alternative in 2100.

Table 5.4.2-8. Cumulative Impacts on CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level rise for GCAM 6.0[a] for Selected Alternatives[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 - No Action	1.5	463.33	527.73	643.45	0.694	1.005	1.506	36.94
	2.0	466.74	534.33	658.72	0.885	1.294	1.971	47.83
	2.5	469.80	540.41	673.33	1.058	1.562	2.415	58.97
	3.0	472.56	546.00	687.29	1.216	1.810	2.838	70.22
	4.5	479.39	560.37	725.55	1.611	2.456	3.998	103.79
	6.0	484.62	571.96	759.36	1.920	2.984	5.037	136.36
Alt. 3 - Preferred	1.5	463.18	527.31	642.54	0.694	1.004	1.504	36.91
	2.0	466.59	533.91	657.79	0.885	1.293	1.968	47.78
	2.5	469.65	539.98	672.37	1.058	1.561	2.412	58.91
	3.0	472.41	545.57	686.31	1.215	1.809	2.834	70.15
	4.5	479.24	559.93	724.52	1.611	2.453	3.993	103.68
	6.0	484.48	571.51	758.28	1.920	2.982	5.031	136.21
Reduction Under Preferred Alternative Compared to the No Action Alternative								
	1.5	0.15	0.42	0.91	0.000	0.001	0.002	0.03
	2.0	0.15	0.42	0.93	0.000	0.001	0.003	0.05
	2.5	0.15	0.43	0.95	0.000	0.001	0.003	0.06
	3.0	0.15	0.43	0.97	0.000	0.002	0.004	0.07
	4.5	0.15	0.44	1.03	0.000	0.002	0.005	0.11
	6.0	0.15	0.44	1.09	0.000	0.002	0.006	0.15

Notes:

[a] Sea-level rise results are based on the regression analysis described in section 5.3.3 Methods for Estimating Climate Effects using GCAM 6.0.

[b] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[c] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986-2005.

Table 5.4.2-9. Cumulative Impacts on CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level rise for GCAM Reference[a] for Selected Alternatives[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 - No Action	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70
Alt. 3 – Preferred	1.5	469.46	545.67	736.53	0.740	1.127	1.888	41.01
	2.0	472.94	552.66	754.52	0.941	1.445	2.448	52.70
	2.5	476.07	559.09	771.69	1.122	1.737	2.978	64.47
	3.0	478.89	565.01	788.09	1.287	2.007	3.480	76.22
	4.5	485.85	580.18	833.20	1.698	2.705	4.863	110.83
	6.0	491.19	592.43	873.72	2.019	3.277	6.164	144.56
Reduction Under Preferred Alternative Compared to the No Action Alternative								
	1.5	0.15	0.43	0.95	0.000	0.001	0.002	0.03
	2.0	0.15	0.43	0.97	0.000	0.001	0.003	0.04
	2.5	0.15	0.43	1.00	0.000	0.001	0.003	0.05
	3.0	0.15	0.44	1.02	0.000	0.002	0.004	0.07
	4.5	0.15	0.44	1.08	0.000	0.002	0.005	0.10
	6.0	0.15	0.45	1.16	0.000	0.002	0.007	0.14

Notes:

[a] Sea-level rise results are based on the regression analysis described in section 5.3.3 Methods for Estimating Climate Effects using a hybrid relation based on RCP 6.0 and RCP 8.5.

[b] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[c] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986-2005.

The sensitivity of the simulated global mean surface temperatures for 2040, 2060, and 2100 varies over the simulation period, as shown in Table 5.4.2-7. In 2040, the impact is low due primarily to the rate at which global mean surface temperature increases in response to increases in radiative forcing. In 2100, the impact is larger due to climate sensitivity and change in emissions. The impact on global mean surface temperature due to assumptions concerning global emissions of GHGs is also important. The scenarios with the higher global emissions of GHGs, such as the GCAM Reference scenario, have a lower reduction in global mean surface temperature, and the scenarios with lower global emissions, such as RCP4.5, have a higher reduction. This is in large part due to the non-linear and near-logarithmic relationship between radiative forcing and CO_2 concentrations. At high emissions levels, CO_2 concentrations are high; therefore, a fixed reduction in emissions yields a lower reduction in radiative forcing and global mean surface temperature.

The sensitivity of simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 5.4.2-7 through Table 5.4.2-9. Scenarios with lower climate sensitivities have lower increases in sea-level rise; the increase in sea-level rise is lower under the Preferred Alternative than it would be under scenarios with higher climate sensitivities. Conversely, scenarios with higher climate sensitivities have higher sea-level rise; the increase of sea-

level rise is higher under the Preferred Alternative than it would be under scenarios with lower climate sensitivities. Higher global GHG emissions scenarios have higher sea-level rise, but the impact of the Preferred Alternative is less than in scenarios with lower global emissions. Conversely, scenarios with lower global GHG emissions have lower sea-level rise, although the impact of the Preferred Alternative is greater than in scenarios with higher global emissions.

5.5 Health, Societal, and Environmental Impacts of Climate Change

5.5.1 Introduction

As described in Section 5.4, ongoing emissions of GHGs from many sectors, including transportation, affect global CO_2 concentrations, temperature, precipitation, and sea level. This section describes how these effects can translate to impacts on key natural and human resources.

Although the action alternatives NHTSA is considering would decrease growth in GHG emissions, they alone would not prevent climate change. Instead, they would result in reductions in the anticipated increases of global CO_2 concentrations and associated impacts, including changes in temperature, precipitation, and sea level that are otherwise projected to occur under the No Action Alternative.

By limiting increases in CO_2 concentrations, the action alternatives would also contribute to reducing the impact of climate change across resources that would otherwise occur under the No Action Alternative. Similarly, to the extent the action alternatives would result in reductions in projected increases in global CO_2 concentrations, the Proposed Action would contribute to reducing the risk of crossing atmospheric CO_2 concentration thresholds that trigger abrupt changes in Earth's systems—thresholds known as "tipping points" (*see* Section 5.5.1.10)—from what that risk would otherwise be under the No Action Alternative. Delaying mitigation in the short term will require more stringent reductions in the future to limit climate change impacts.

NHTSA's assumption is that reductions in climate effects relating to temperature, precipitation, and sea-level rise would reduce impacts on affected resources. However, the magnitude of the changes in climate effects that the alternatives would produce (*see* Section 5.4) are too small to address quantitatively in terms of their impacts on the specific resources discussed below.[37] Consequently, the discussion of resource impacts in this section does not distinguish among the alternatives; rather it provides a qualitative review of projected impacts (where the potential benefits of reducing GHG emissions would result in reducing these potential impacts) and the magnitude of the risks involved in climate change. Nonetheless, it is clear that these resources are likely to be beneficially affected to some degree by the reduced climate change impacts expected to result from the action alternatives.

[37] This section does not compare the projected reductions in global climate effects in Section 5.4 to the national-, regional-, or local-scale reductions in climate effects presented in Section 5.5. The projected reductions in global climate effects do not translate to identical projected reductions at the national, regional, or local scale. In addition, the projected reductions in global climate effects for each of the alternatives are too small to incorporate into a regional/local-scale analysis, which would likely introduce uncertainties at the same magnitude or more than the projected change itself (i.e., the projected change would be within the noise of the model). However, it is understood that climate change is occurring due to the emissions from a collection of sources, and that mitigation across these sources is necessary to curtail additional warming. Although the projected reductions in CO_2 and climate effects in Section 5.4 are small compared to total projected future climate change, they are quantifiable and directionally consistent, and will contribute to reducing the risks associated with climate change from what they would otherwise be under the No Action Alternative. While NHTSA does quantify the reductions in monetized damages attributable to each action alternative (in the SCC analysis), many specific impacts on health, society, and the environment (e.g., number of species lost) cannot be estimated quantitatively. Therefore, NHTSA provides a detailed discussion of the impacts of climate change on various resource sectors in this section.

This section also briefly describes ongoing adaptation efforts for various resource areas. While mitigation efforts are required to lower the overall risk of triggering large or accelerating transitions to significantly different physical states within Earth's systems, efforts to adapt to climate change are also necessary to increase the resilience of human and natural systems to the adverse risks of climate change. As a measure of the importance of current and potential climate change impacts, the Obama Administration has identified adaptation as a critical need through Executive Order 13514. This Order requires federal agencies to evaluate agency climate change risks and vulnerabilities to manage both the short- and long-term effects of climate change on the agency's mission, programs, and operations. Pursuant to this Order, CEQ issued a set of Implementing Instructions for Federal Agency Adaptation Planning that informed agencies how to integrate climate change adaptation into their planning, operations, policies, and programs (CEQ 2012).

The health, societal, and environmental impacts discussion is divided into two parts: Section 5.5.1 discusses the sector-specific impacts of climate change, while Section 5.5.2 discusses the region-specific impacts of climate change. Section 5.5.1 further discusses ongoing adaptation efforts for various resource areas.

5.5.2 Sectoral Impacts of Climate Change

This section is divided into discussions of sector-specific impacts of climate change. Specifically, Sections 5.5.1.1 through 5.5.1.9 address cumulative impacts on the following key natural and human resources:

- Freshwater resources (the availability, resource management practices, and vulnerabilities of fresh water as a function of climate).
- Terrestrial and freshwater ecosystems (existing and potential vulnerabilities and benefits of the respective species and communities in response to climate change).
- Ocean systems, coastal and low-lying areas (the interplay among climate, environment, species, and communities in coastal and open-ocean waters, including coastal wetlands and coastal human settlements).
- Food, fiber, and forest products (the environmental vulnerabilities of farming, forestry, and fisheries to climate change).
- Urban areas (how climate change might affect human institutions and systems focusing on urban communities, including industrial and service sectors; transportation systems; energy production; and financial, cultural, and social institutions).
- Rural areas (how climate change might affect human institutions and systems, focusing on rural communities).
- Human health (how a changing climate might affect human mortality and morbidity).
- Human security (how climate change could affect livelihoods, cultures, migration and mobility, armed conflict, and state integrity and geopolitical rivalry).
- Stratospheric ozone (how climate change might affect ozone concentrations in the stratosphere).

Section 5.5.1.10 summarizes tipping points, abrupt climate change, and potential thresholds; it is cross-cutting because it addresses some of the resources in Sections 5.5.1.1 through 5.5.1.9.

Sections 5.5.1.1 through 5.5.1.9 first summarize findings related to the consequences of observed and projected climate change in the United States and globally on each resource, drawing largely from recent reports including the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 2013a, 2013b, 2014a, 2014b) and the U.S. Global Climate Research Program (GCRP) National

Climate Assessment (NCA) Report (GCRP 2014). The sections conclude with reviews of the potential to adapt to climate change and the extent to which adaptation could reduce climate change risks. Because adaptation measures will become increasingly expensive in the face of large magnitude climate changes, and there are limits to systems' abilities to adapt, adaptation cannot be considered a substitute for mitigation actions designed to limit climate change impacts.

Although the approach is systematic, these topics do not exist in isolation, and there is some overlap between discussions. The sections generally reflect the organization of topic areas in the climate literature, notably by the IPCC and the GCRP, primary sources for much of the information in this section.

To reflect the likelihood of climate change impacts accurately for each sector, NHTSA references and uses the IPCC uncertainty guidelines (*see* Section 5.1.1). This approach provides a consistent methodology to define confidence levels and percent probability of a predicted outcome or impact. This is primarily applied for key IPCC findings where the IPCC has defined the associated uncertainty with the finding (other sources generally do not provide enough information or expert consensus to elicit uncertainty rankings).

In addition to the recent seminal reports from the IPCC and GCRP, additional reports from the GCRP and such agencies as the National Research Council have been included. NHTSA similarly relies on panel reports because they have assessed numerous individual studies to draw general conclusions about the state of science and have been reviewed and formally accepted by, commissioned by, or in some cases authored by U.S. government agencies and individual government scientists. This material has been well vetted, both by the climate change research community and by the U.S. government. In many cases, it reflects the consensus conclusions of expert authors. In addition, as the state of the science continues to evolve since the release date of these reports, the findings from these reports have been supplemented with recent (2013 and 2014) peer-reviewed information. Peer-reviewed information prior to 2013 is included for additional findings that may support or supplement key findings presented by the seminal and panel reports.

5.5.2.1 Freshwater Resources

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on freshwater resources in the United States and globally. Over 70 percent of the surface of the Earth is covered by water, but only 2.5 percent is freshwater. Respectively, freshwater contributions include permanent snow cover in the Antarctic, the Arctic, and mountainous regions (68.7 percent); groundwater (29.9 percent); and freshwater in lakes, reservoirs, and river systems (0.26 percent) (UNESCO 2006).

Other important non-climate related drivers of change that impact the quantity, quality, availability, and use of freshwater—such as demographic, industrial, land use, and technological changes—are not directly addressed in this section. Note that historically, non-climate drivers have significantly impacted freshwater resources; understanding the contribution of these different drivers to changes in the freshwater resource provides important information regarding how to effectively and efficiently address (and anticipate) changes. For example, while increases in precipitation and intense rainfall are projected to decrease freshwater quality in parts of the United States, strategies that aim to reduce sediment, nutrient, and contaminant loads at the source remain the most effective management responses. Strategies that reduce water demands (e.g., concerning agriculture, there are ways to get the water to the crop that are more efficient and thereby reduce overall demand) can also be employed in areas subject to increasing water scarcity.

5.5.2.1.1 Summary

Overall, the most recent freshwater resources studies cited herein confirm previous results and add to the growing body of modeling results and field observations that indicate substantial impacts on freshwater resources, and implications on their sustainability, as a result of climate change. In general, global warming is expected to cause wet regions to become wetter and dry regions to become drier globally and within the United States (IPCC 2014a, GCRP 2014, Liu and Allen 2013). Potential risks to freshwater resources are expected to increase with increasing GHG emissions; for example, higher emissions are projected to result in less renewable water for greater numbers of people (IPCC 2014b). Although some positive impacts are anticipated, including reductions in water stress and increases in water quality in some areas as a result of increased runoff, the negative impacts are expected to outweigh positive impacts (IPCC 2014b, GCRP 2014).

Globally, widespread observations and evidence of changes in flood magnitude and frequency or of surface water and groundwater drought frequency as a result of climate change do not exist; however, projections imply increases in both drought risk (particularly in dry regions) and flood risk globally and within the United States. Changes in climate will affect water demand, including expected significant increases in irrigation water demand for some regions. Projected water shortages, general variability in supply, and increasing flood risk pose serious challenges for water resource management (GCRP 2014).

5.5.2.1.2 Observations and Projections of Climate Impacts

<u>Precipitation, Stream Flow, Runoff, and Surface Water</u>

In recent decades, annual average precipitation increases have been observed across the Midwest, Great Plains, the Northeast, and Alaska, while decreases have been observed in Hawaii and parts of the Southeast and Southwest (Walsh et al. 2014). Globally, for mid-latitude land areas of the northern hemisphere, annual average precipitation has likely increased since 1901. For other latitudinal zones, long-term trends in average precipitation are uncertain due to data quality, data completeness, or disagreement among available estimates (IPCC 2014a).

Detected trends in streamflow and runoff are generally consistent with observed regional changes in precipitation and temperature (IPCC 2014b). In the United States (1951 to 2002), increases in runoff were observed in the Mississippi and Missouri regions, while runoff decreases were observed in the Pacific Northwest and southern Atlantic-Gulf regions (IPCC 2014b citing Kalra et al. 2008, GCRP 2014 citing Luce and Holden 2009), with no clear trends in much of the rest of the continental United States (GCRP 2014 citing McCabe and Wolock 2011). A recent study (Patterson et al. 2013) found climate contributed to increased streamflow (average of 14 percent) in the South Atlantic over the time period 1970–2005.

In a global analysis of simulated streamflows (1948 to 2004), about one-third of the top 200 rivers showed significant trends in discharge; 45 recorded decreases and only 19 recorded increases (IPCC 2014b citing Dai et al. 2009). Globally, in regions with seasonal snow storage, warming has led to earlier spring discharge maxima and increased winter flows because more winter precipitation falls as rain instead of snow (IPCC 2014b citing Clow 2010, Korhonen and Kuusisto 2010, Tan et al. 2011).

The projected patterns of runoff change (and the uncertainty) are largely driven by projected changes in precipitation. Average annual precipitation is projected to increase across the northern United States and decrease in the southern United States, especially the Southwest (GCRP 2014 citing Kennedy et al. 2010). Average global precipitation is projected to increase over the next century; generally, wet places are expected to get wetter and dry places are expected to get drier (IPCC 2014a).

Basins in the southwestern United States and southern Rockies are projected to experience gradual runoff declines during this century. Basins in the Northwest to north-central United States are projected to experience little change through the middle of this century and increases by late this century. Projected changes in runoff differ by season, with cool season runoff increasing over the west coast basins from California to Washington and over the north-central United States. Basins in the southwestern United States and southern Rockies are projected to see little change to slight decreases in the winter months. Warm season runoff is projected to decrease substantially over a region spanning southern Oregon, the southwestern United States, and southern Rockies, and change little or increase slightly north of this region (GCRP 2014).

Globally, average annual runoff is projected to increase at high latitudes and in the wet tropics and to decrease in most dry tropical regions. However, for some regions there is considerable uncertainty in the magnitude and direction of change, specifically in China, south Asia, and large parts of South America. Continued loss of glacier ice implies a shift of peak discharge from summer to spring, except in monsoonal catchments, and possibly a reduction of summer flows in the downstream parts of glacierized catchments (IPCC 2014b).

Groundwater

In large regions of the Southwest, Great Plains, Midwest, Florida, and some other coastal areas, groundwater aquifers are susceptible to the combined stresses of climate and water use changes. However, both globally and in the United States, attribution of observed changes in groundwater level, storage, or discharge to climatic changes is difficult due to additional influences of land use changes and groundwater abstractions (IPCC 2014b citing Stoll et al. 2011), and the extent to which groundwater abstractions have already been affected by climate change is not known.

Ensemble studies of the potential impact of climate change on groundwater recharge and partially also on groundwater levels were done for the globe (IPCC 2014b citing Portmann et al. 2013), the Pacific coast of the United States and Canada (IPCC citing Allen et al. 2010), the semi-arid High Plains aquifer of the United States (IPCC 2014b citing Crosbie et al. 2013b, Ng et al. 2010), and other regions. The range over the climate models of projected groundwater changes was large, from significant decreases to significant increases for the individual study areas, and the range of percentage changes of projected groundwater recharge mostly exceeded the range of projected precipitation changes. Both globally and in the United States, sea-level rise, storms and storm surges, and changes in surface water and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands (GCRP 2014).

Snow, Ice Cover, Permafrost, and Glaciers

Rising temperatures across the United States have reduced lake ice, sea ice, glaciers, and seasonal snow cover over the last few decades (GCRP 2014 citing AMAP 2011). Sea ice in the Arctic has decreased dramatically since the late 1970s, particularly in summer and autumn. Glaciers are retreating and/or thinning in Alaska and in the lower 48 states. In addition, permafrost temperatures are increasing over Alaska and much of the Arctic. In most parts of the world, glaciers are losing mass (Gardner et al. 2013). Nearly all glaciers are too large for equilibrium with the present climate, committing them to change during much of the 21st century. Decreases in the extent of permafrost and increases in its average temperature are widely observed (IPCC 2014a citing Rabassa 2009).

Nearly all studies to date published in the peer-reviewed literature agree that if heat-trapping gas concentrations continue to rise, lake ice, sea ice, glaciers, and seasonal snow cover will be reduced (IPCC 2014a); for example, an essentially ice-free Arctic Ocean is expected sometime during this century (for

example, Stroeve et al. 2012). In the United States, Great Lakes ice should follow a similar trajectory. Basins watered by glacial melt in the Sierra Nevada, Glacier National Park, and Alaska may experience increased summer riverflow in the next few decades, until the amounts of glacial ice become too small to contribute to riverflow (GCRP citing Basagic and Fountain 2011, Hall and Fagre 2003, Hodgkins et al. 2005).

Extreme Rainfall, Floods, and Droughts

The number and intensity of very heavy precipitation events have been increasing significantly across most of the United States. For example, from 1950 to 2007, daily precipitation totals with 2-, 5-, and 10-year average recurrence periods increased in the Northeast and western Great Lakes (GCRP 2014 citing DeGaetano 2009, Mishra and Lettenmaier 2011). According to the NCA report, river floods have been increasing in the Northeast and Midwest and decreasing in the Southwest and Southeast (GCRP 2014 citing Villarini et al. 2009, Villarini and Smith 2010, Hirsch and Ryberg 2012, Gutowski et al. 2008, and Karl and Knight 1998). However, GCRP (2014a) cites Hirsch and Ryberg (2012) in concluding that there is no strong evidence for trends in observed flooding in the United States. Hirsh and Ryberg (2012) took a different approach than other studies in focusing on finding statistical evidence of a historical relationship between global mean CO_2 and flood magnitudes in the coterminous United States, and while they did not find strong statistical evidence for flood magnitudes increasing, they found a statistically significant negative relationship between global mean CO_2 and flood magnitudes in the southwest. These decreases are consistent with the NCA report findings, and are not surprising, as short duration very heavy precipitation events often occur during the summer and autumn when rivers are generally low.

There is limited evidence that anthropogenic climate change has affected the frequency and magnitude of floods at a global scale (Kundzewicz et al. 2013). The strength of the evidence is limited mainly by lack of long-term records from unmanaged catchments. Moreover, in the attribution of detected changes it is difficult to distinguish the roles of climate and human activities. However, recent detection of trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at a regional scale. More locations show increases in heavy precipitation than decreases (Seneviratne et al. 2012). Flood damage costs worldwide have been increasing since the 1970s, although this is partly due to increasing exposure of people and assets (Handmer et al. 2012).

In the United States, there is no evidence that surface water and groundwater drought frequency has changed over the last few decades as a result of climate change. Droughts occur on time scales ranging from season-to-season to multiple years and even multiple decades. There has been no universal trend detected in the overall extent of drought across the continental United States since 1900. However, in the Southwest, wide-spread drought in the past decade has reflected both precipitation deficits and higher temperatures in ways that resemble projected changes (GCRP 2014 citing Cayan et al. 2010, Hoerling et al. 2012). Globally, meteorological (rainfall) and agricultural (soil moisture) droughts have become more frequent since 1950 in some regions, including southern Europe and western Africa (IPCC 2013 citing Seneviratne et al. 2012). In simulations of drought at the global scale in 1963–2000, strong correlations were noted between El Niño–Southern Oscillation events and hydrological droughts, and — particularly in dry regions — low correlations between meteorological and hydrological droughts, which suggests that hydrological droughts cannot necessarily be inferred from rainfall deficits (van Huijgevoort et al. 2013).

The number and magnitude of the heaviest precipitation events is projected to increase everywhere in the United States (GCRP 2014 citing Kharin et al. 2013). Heavy precipitation events that historically occurred once in 20 years are projected to occur as frequently as every 5 to 15 years by late this century

(GCRP 2014 citing Groisman et al. 2012). Floods that are closely tied to heavy precipitation events, such as flash floods and urban floods, as well as coastal floods related to sea-level rise and the resulting increase in storm surge height and inland impacts, are expected to increase (GCRP 2014). Globally, projections imply variations in the frequency of floods and increases in global flood risk in the future partly due to climate change; as the level of GHG emissions rises, increasing numbers of people are expected to be exposed to 100-year flood events (IPCC 2014c).

Dry spells are also projected to increase in length in most regions, especially in the southern and northwestern portions of the contiguous United States. Projected changes in total average annual precipitation are generally small in many areas, but both wet and dry extremes (heavy precipitation events and length of dry spells) are projected to increase substantially almost everywhere. Long-term (multi-seasonal) drought conditions are also projected to increase in parts of the Southeast and possibly in Hawaii and the Pacific Islands (GCRP 2014). Except in the few areas where increases in summer precipitation compensate, summer droughts are expected to intensify almost everywhere in the continental United States (GCRP 2014 citing Trenberth et al. 2004) due to longer periods of dry weather and more extreme heat (GCRP 2014 citing Gao et al. 2011), leading to more moisture loss from plants and earlier soil moisture depletion in basins where snowmelt shifts to earlier in the year.

Climate change is likely to increase the frequency of droughts in presently dry regions by the end of this century (under the high [RCP8.5] scenario), which in turn is likely to increase the frequency of short hydrological droughts (less surface water and groundwater) in these regions. Very few studies have considered variations over time in hydrological (streamflow) drought, largely because there are few long records from catchments without direct human interventions. A recent study (Prudhomme et al. 2014) using an ensemble of 35 simulations showed a likely increase in the global severity of drought by the end of 21st century, with regional hotspots including South America and Central and Western Europe in which the frequency of drought increases by more than 20 percent.

Water Quality

There are well established links among fertilizer use, nutrient pollution, and river discharge, and many studies show that recent increases in rainfall in several regions of the United States have led to higher nitrogen amounts carried by rivers (Northeast, California, and Mississippi Basin) (GCRP citing Barnett et al. 2008, Bonfils et al. 2008, Das et al. 2009, Hidalgo et al. 2009, Pierce et al. 2008, Pierce and Cayan 2013, Gan et al. 2013, Hodgkins and Dudley 2006a, Hodgkins and Dudley 2006b, Feng and Hu 2007). Over the past 50 years, due to both climate and land use change, the Mississippi Basin is yielding an additional 32 million acre-feet of water each year laden with materials washed from its farmlands. This flows into the Gulf of Mexico, which is the site of the nation's largest low oxygen "dead" zone (GCRP 2014 citing Hodgkins et al. 2002).

Globally, most observed changes of water quality due to climate change are known from isolated, short-term studies, mostly of rivers or lakes in high-income countries. The most frequently reported change is more intense eutrophication (i.e., an increase in phosphorus and nitrogen in freshwater resources) and algal blooms (i.e., excessive growth of algae) at higher temperatures, or shorter hydraulic retention times and higher nutrient loads resulting from increased storm runoff. Positive reported impacts include reductions in the risk of eutrophication when nutrients were flushed from lakes and estuaries by more frequent storms and hurricanes (IPCC 2014b citing Pearl and Huisman 2008). For rivers, all reported impacts on water quality were negative. Studies of impacts on groundwater quality are limited and mostly report elevated concentrations of fecal coliforms during the rainy season or after extreme rain events (IPCC 2014b citing Auld et al. 2004, Curriero et al. 2001, Jean et al. 2006, Seidu et al. 2013,

Tumwine et al. 2002, 2003). In general, the linkages between observed impacts on water quality and climate should be interpreted cautiously and at the local level.

Globally, and within the United States, there are few projections of the impacts of climate change on water quality; where available, their uncertainty is high. Areas of the United States that are projected to see increases in precipitation, and increases in intense rainfalls, like the Northeast, Midwest, and mountainous West (GCRP 2014 citing Roy et al. 2012), are expected to see increases in excess nutrients, dissolved oxygen concentrations, and sediments transported to rivers. One study suggests that downstream and coastal impacts of increased nitrogen inputs could be profound for the Mississippi Basin (Justić et al. 1996). Rising air temperatures, increased frequency and duration of droughts, and associated low water levels increase nutrient concentrations and residence times in streams, potentially increasing the likelihood of harmful algal blooms and low oxygen conditions (GCRP 2014 citing Whitehead et al. 2009). Concerns over such impacts and their potential link to climate change are rising for many U.S. regions including the Great Lakes (GCRP citing Stumpf et al. 2012), Chesapeake Bay (GCRP 2014 citing Howarth et al. 2006), and the Gulf of Mexico (GCRP 2014 citing Justić et al. 2005, McIsaac et al. 2002, Godsey et al. 2009). Changes in sediment transport are expected to vary regionally and by land-use type, with potentially large increases in some areas (GCRP 2014 citing Nearing 2005), resulting in alterations to reservoir storage and river channels, affecting flooding, navigation, water supply, and dredging.

5.5.2.1.3 Adaptation

Climate change affects water supply, demand, and the ways water is used within and across regions and economic sectors. In the United States, the Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand. Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. Increasing flood risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the United States. In addition, climate change is projected to reduce raw water quality, posing risks to drinking water quality even with conventional treatment (IPCC 2014b).

Climate change challenges water management because it invalidates stationarity —the perception that climate varies around a predictable mean based on the experience of the last century. A move away from stationary conditions suggests that past management practices will become increasingly ineffective and that water management can benefit by the adoption of iterative, risk-based, and adaptive approaches. Given the uncertainty associated with climate change, adaptation planning often involves anticipatory scenario-based planning and the identification of flexible, low-regrets strategies to maximize resilience. In the United States and globally, current and projected impacts of climate change on water resources have sparked several responses by water resource managers that can be built on. In 2011, federal agencies, which manage most of the freshwater resources in the United States, worked with stakeholders to develop a National Action Plan for managing freshwater resources in a changing climate to help ensure adequate freshwater supplies, while also protecting water quality, human health, property, and aquatic ecosystems (ICCATF 2011). Water utilities are determining ways to adjust operation and maintenance schedules. Water conservation and demand management are also being promoted as important nonstructural, low-regrets approaches for managing water supply. Barriers to progress include lack of human and institutional capacity, financial resources, awareness, and communication (IPCC 2014b citing Browning-Aiken et al. 2007, Burton 2008, Butscher and Huggenberger 2009, Zwolsman et al. 2010).

5.5.2.2 Terrestrial and Freshwater Ecosystems

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on the terrestrial and freshwater ecosystems in the United States and globally.

Ecosystems include all living organisms and their environs that interact as part of a system (GCRP 2014 citing Chapin et al. 2011). These systems are often delicately balanced and sensitive to internal and external pressures due to both human and nonhuman influences. Ecosystems are of concern to society because they provide beneficial "ecosystem services" such as jobs (e.g., from fisheries and forestry), fertile soils, clean air and water, recreation, and aesthetic value (GCRP 2014 citing Millennium Ecosystem Assessment 2005).

5.5.2.2.1 Summary

Terrestrial and freshwater ecosystems in the United States and around the world are experiencing rapid and observable changes. Steadily warming temperatures and rising atmospheric CO_2 concentration, as well as changing precipitation patterns, are already leading to shifting species ranges and earlier spring migrations and are threatening the ability of existing habitats to thrive (GCRP 2014, IPCC 2014b). Climate change is also affecting the relative timing of species' life-cycle events, referred to as phenology, which can upset existing species dependencies and predator–prey interactions. Terrestrial and freshwater ecosystems are also affected by wildfires, insect outbreaks, and changes in human activity such as land use change, hydrologic modification, and pollution. The ecosystems addressed in this section include terrestrial ecosystems, such as forests, grasslands, shrublands, savanna, and tundra; aquatic ecosystems, such as rivers, lakes, and ponds; and freshwater wetlands, including marshes, swamps, and bogs.

5.5.2.2.2 Observations and Projections of Climate Impacts on Ecosystems

<u>Phenology</u>

Recent global satellite and ground-based data further support conclusions from earlier reports (including IPCC AR4) that indicated that phenology shifts have been observed, particularly across temperate latitudes of the northern hemisphere. These shifts include earlier spring events, such as breeding, budding, flowering, and migration, which have been observed in hundreds of plant and animal species (IPCC 2014b citing Menzel et al. 2006, Cleland et al. 2007, Parmesan 2007, Primack et al. 2009, Cook et al. 2012a, Peñuelas et al. 2013). Leaf unfolding and flowering in spring and summer have, on average, advanced by 1 to 3 days per decade in Europe, North America, High Arctic Regions, and Asia over the past 35 to 152 years (study-dependent) (IPCC 2014 citing Cook et al. 2008, Cook et al. 2012b, Menzel et al. 2006, Primack et al. 2009, Ma and Zhou 2012, Høye et al. 2007).

For amphibians, increasing regional temperatures are also associated with earlier calling and mating and shorter time to maturity. In the eastern United States, there could be as much as a 50 percent turnover in amphibian species by the end of the century as a result of changes in climate due to unfavorable future conditions for current species and to phenological mismatches that result in unfavorable breeding and egg-laying conditions (GCRP 2014 citing Lawler et al. 2010 and Todd et al. 2011). The seasonal timing of bird migration and egg-laying has also changed, associated with the increase of temperature in breeding grounds and migration routes; such changes are projected to continue (GCRP 2014 citing Miller-Rushing et al. 2008, Van Buskirk et al. 2008, Jones and Cresswell 2010, Swanson and Palmer 2009, and Wiebe and Gerstmar 2010; IPCC 2014b citing Thorup et al. 2007). In the northern hemisphere, earlier egg-laying dates (by about 3.5 days per decade) have been observed for 41 species

(IPCC 2014b citing Parmesan 2007). A mismatch in timing between food abundance, breeding, and migration is also associated with decreased average egg size (Potti 2008).

Recent studies support the conclusions of earlier work indicating that the phenology of plant and animal species will continue to change in regions that experience warmer annual average temperatures and earlier spring weather.

Species' Range and Ecosystem Shifts and Localized Extirpation or Global Extinction of Species

Species respond to stressors such as climate change by phenotypic[38] or genotypic[39] modifications, migrations, or extinction (IPCC 2014 citing Dawson et al. 2011, Bellard et al. 2012, Peñuelas et al. 2013). Changes in the distribution of species have occurred across a wide range of taxonomic groups and geographical locations. Recent studies have reinforced earlier conclusions in the IPCC AR4 that over the past several decades, a pole-ward (in latitude) and upward (in elevation) extension of various species' ranges has been observed that is probably attributable to increases in temperature (IPCC 2014b). In both terrestrial and freshwater ecosystems, plants and animals are moving up in elevation—at approximately 36 feet per decade—and in latitude—at approximately 10.5 miles per decade (GCRP 2014 citing Chen et al. 2011). In some mountainous areas of the northern hemisphere, including in Alaska, tree lines have shifted to higher altitudes over the past century. Many northern communities have seen shifts at forest/tundra, broadleaf/conifer, and shrubland/conifer boundaries due to warming (GCRP 2014 citing Beck et al. 2001, Dial et al. 2007, Lloyd and Fastie 2003, Suarez et al. 1999, Wilmking et al. 2004, Millar et al. 2004, Beckage et al. 2008, Allen et al. 1998).

Climate-related extinctions are linked to the following factors: physiological tolerances for temperature, other physical factors (fire disturbance, melting ice caps, sea-level rise), decreases in species upon which other species rely, increases in invasive species, and temporal mismatches (such as short windows for migration, and breeding periods that no longer coincide with peak bloom periods which in turn result in food shortages—see phenology discussion) (Cahill et al. 2012). Studies agree that localized extinctions ("extirpations") of species are expected to continue, and probably occur more quickly, over the coming century. Over the 21st century, species range shifts, as well as extirpations, are likely to result in significant changes in ecosystem plant and species mixes, creating entirely new ecosystems (GCRP 2014 citing Staudt et al. 2013, Sabo et al. 2010, Cheung et al. 2009, Lawler et al. 2009, and Stralberg et al. 2009). Since the IPCC AR4, studies have confirmed with *high confidence* that climate change will exacerbate the extinction risk for terrestrial and freshwater species over the 21st century; however, there is low agreement on the number of species that are at risk (ranging from 1 to 50 percent) (IPCC 2014b).

Of particular concern for aquatic species, including fish, is that the combination of increased water demand (withdrawals) and changes in climate is likely to result in freshwater habitat loss. In the United States, under the moderate (A1B) emissions scenario, close to half of the western states' trout habitat would be lost by 2080 (GCRP 2014 citing Wenger et al. 2011). Previously uncommon species of fish, such as Pacific salmon, have been observed in aquatic systems of the Canadian Arctic in recent years, as a result of expanded ranges from warming waters (ACIA 2004). There is *high confidence* that some fish will be threatened with extinction over the long term, as the pace of warming in rivers and lakes exceeds the pace with which fish are able to migrate to more suitable habitats (IPCC 2014b).

[38] Referring to an organism's observable traits, such as color or size.

[39] Referring to an organism's genetic makeup.

Additionally, in areas that experience heavier or more frequent precipitation events, an increase in phosphorus and nitrogen in freshwater resources (eutrophication) due to increased agricultural runoff is probable in the Northeast, California, and Mississippi Basin (GCRP 2014 citing Howarth et al. 2012, Howarth et al. 2006, Sobota et al. 2009, Justić et al. 2005, and McIsaac et al. 2002). Sources for these nutrients typically include agricultural fertilizers and sewage. The effects of eutrophication include excessive growth of algae (algal blooms), which reduce dissolved oxygen in the water, causing plants, fish, and invertebrates to die. Often, as native plant and animal species die, they are replaced with invasive species, changing the basic makeup of the ecosystem.

Species Morphology[40] and Reproduction

Changes in morphology and reproductive rates have been attributed to climate change. For example, the egg sizes of some bird species are changing with increasing regional temperatures (Potti 2008). At least one study indicates that birds in North America are experiencing decreased body size due to changes in climate (Van Buskirk et al. 2010). Increases in predatory populations as a result of regional warming put some bird populations at risk due to increased vulnerability of their eggs to predators; additionally, declines in available habitat put birds at risk when they are unable to find appropriate nesting and egg-laying spots. This is especially of concern for seabirds and birds that rely on rainforest ecosystems (Wormworth and Mallon 2010). Many northern insects have a 2-year life cycle, and warmer winter temperatures allow a larger fraction of overwintering larvae to survive. For example, the invasive mountain pine beetle has expanded its range in the western United States and Canada into areas previously considered too cold for its survival (IPCC 2014 citing Raffa et al. 2008).

Changes in the Carbon Storage Capacity of Terrestrial Ecosystems

Terrestrial plants store atmospheric CO_2; increasing terrestrial plant mass will increase carbon storage, at least over the short term. In the first decade of the 21st century, net primary productivity among terrestrial systems was estimated to be 5 percent greater than pre-industrial productivity, which is equivalent to increased carbon storage of about 2.6 petagrams (Pg, or 1015 grams) (IPCC 2014b). Many studies have indicated that accelerated tree growth occurred over the 20th century (IPCC 2014 citing Briffa et al. 2008), which is associated with increased temperature that supports vegetation growth and can also be associated with direct CO_2 fertilization (IPCC 2014b). Conversely, in areas experiencing extended drought (such as the western United States in 2014) water stress results in decreased tree growth (IPCC 2014b). For some ecosystems, the factors that affect the balance between carbon storage or carbon source are not well understood.

A recent study evaluated the capacity of the Greater Yellowstone Ecosystem (GYE) conifer forests to act as a carbon storage pool under changing climate conditions and new fire regimes. Using climate projections downscaled to the ecosystem, and using these projections in the CENTURY model (a dynamic ecosystem process model), the authors simulated carbon storage in the GYE conifer forests over the 21st century. They found that more than one occurrence of wildfire within a 90-year period will cause lodgepole pines to shift from acting as a net carbon sink to a net carbon source. Although the projected warming conditions will likely increase forest productivity, thereby increasing carbon storage, net storage will not occur at a rate sufficient to recover more than 85 percent of the carbon lost during the initial wildfire. The authors concluded that while the magnitude of the shift is uncertain, the potential of the GYE to store carbon will decline under all warming climate scenarios (IPCC 2014b citing Westerling et al. 2011).

[40] Referring to an organism's structural or anatomical features (e.g., egg size, wing shape, or even of the organism as a whole).

Several recent studies have evaluated terrestrial vegetation productivity and the associated carbon storage in response to changes in carbon, nitrogen, and phosphorous nutrient cycles. The authors indicate that in addition to nitrogen fixation, carbon storage in vegetation is likely to be closely linked to interactions between carbon and phosphorus nutrient cycles. As plants gain more biomass, their net storage of carbon might be limited by nutrient availability in soils (Finzi et al. 2011). Within a few decades, it is possible that changes in temperature and precipitation patterns will exceed nitrogen and CO_2 as key drivers of ecosystem productivity (IPCC 2014b).

Ecological Tipping Points and Biodiversity

A 2010 report by the Convention on Biological Diversity (IPCC 2014b citing Leadley et al. 2010) described ecosystem-wide impacts in the event of the loss of keystone plant and animal species, the introduction of new species, and/or changes to the physical structure of the system (for example, loss of permafrost). Similar to the concept of tipping points in ocean or climate systems discussed in Section 5.5.1.10, ecological tipping points[41] begin with initial changes in a biological system (for example, the introduction of a new predatory animal species to the system due to changes in climate that are favorable to the newly introduced species), which are then amplified by positive feedback loops and can lead to cascading effects throughout the system. The point at which the system can no longer retain stability is a threshold known as a tipping point. Changes in such situations are often long lasting and hard to roll back; managing these conditions is often very difficult (IPCC 2014b citing Leadley et al. 2010). Leadley et al. (2010) evaluated the potential tipping point mechanisms and their impacts on biodiversity and ecosystem services for several ecosystems. Examples include (1) warming tundra that will lower albedo, providing a warming feedback that will result in further thawing of tundra and (2) the large-scale changes in Amazonian rainforests to agricultural lands, resulting in decreased local/regional rains, promoting further decline of trees.

Forest ecosystems and services are at risk of greater fire disturbance when they are exposed to increased warming and drying, as well as declines in productivity and increases in insect disturbances (such as pine beetles). Boreal fire regimes have become more intense in terms of areas burned, length of fire season, and hotter, more energetic fires (IPCC 2014b citing Girardian and Mudelsee 2008, Macias Fauria and Johnson 2008, Kasischke et al. 2010, Turetsky et al. 2011, Mann et al. 2012, and Girardian et al. 2013a). Fires of greater intensity burn soils to greater depths, encouraging replacement of coniferous species with deciduous trees—further enhancing the species shifts due to warming (IPCC 2014 citing Johnstone et al. 2010 and Bernhardt et al. 2011). Cascading effects in forests are possible when fire-related changes in forest composition result in reduced capacity as a carbon sink and lower albedo, both of which factor into further warming, putting forests at even greater risk of fire and dieback (IPCC 2014 citing Bond-Lamberty et al. 2007, Goetz et al. 2007, Welp et al. 2007, Euskirchen et al. 2009, Randerson et al. 2007, Jin et al. 2012, and O'Halloran et al. 2012).

5.5.2.2.3 Adaptation

Ecosystem adaptation to climate change can be the result of human activities intended to protect them or can occur naturally by responses within the ecosystem. In the context of natural resource management, adaptation is about managing changes (GCRP 2014 citing Staudinger et al. 2012, Link et al. 2010, and West et al. 2009). The ability or inability of ecosystems to adapt to change is referred to as adaptive capacity. There could be notable regional differences in the adaptive capacity of ecosystems,

[41] An ecological tipping point is described by IPCC (2014), in reference to the potential for Amazonian ecosystem shifts, as "a large-scale, climate-driven, self-reinforcing transition" of one ecosystem into another type.

and adaptive capacity is moderated by anthropogenic influences and capabilities. The ultimate impact of climate change on ecosystems depends on the speed and extent to which the se systems can adapt to a changing climate.

Some adaptation strategies include habitat manipulation, conserving populations with more genetic diversity and/or behaviors, relocation (or assisted migration), and offsite conservation (such as seed banking and captive breeding) (GCRP 2014 citing Weeks et al. 2011, Peterson et al. 2001, Cross et al. 2013, and Schwartz et al. 2012). Significant modifications to existing ecosystem management practices are probably the most important—as well as the most challenging—changes that are required for adaptation. NCA (2014) indicates that it will be very difficult for existing management goals to be achieved in the face of a changing climate; that is, the effectiveness of existing strategies and approaches is likely to be diminished.

5.5.2.3 Ocean, Coastal, and Low-lying Areas

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on ocean, coastal, and low-lying areas in the United States and globally. Ocean systems cover approximately 71 percent of the Earth's surface and include many habitats that are vital for coastal economies. Coastal systems and low-lying areas include all areas near the mean sea level. Coastal systems consist of both natural systems (i.e., rocky coasts, beaches, barriers, sand dunes, estuaries, lagoons, deltas, river mouths, wetlands, and coral reefs) and human systems (i.e., the built environment, institutions, and human activities) (IPCC 2014b).

Oceans and coastal systems are vulnerable to both warming temperatures and various anthropogenic impacts. A large portion of ocean and coastal ecosystems around the globe has been substantially degraded or lost altogether. The population of individuals living in coastal areas continues to increase worldwide, increasing environmental pressures (e.g., physical alteration, habitat degradation and destruction, water withdrawal, overexploitation, pollution, and the introduction of nonnative species) that threaten the very resources that make the coastal zones desirable. Moreover, climate change has the potential to compound these pressures, leaving these systems particularly vulnerable to warming water temperatures, sea-level rise, water acidification, and increased extreme weather events.

5.5.2.3.1 Summary

Overall, the most recent ocean and coastal systems studies cited herein confirm previous results and add to the growing body of modeling results and field observations that indicate substantial impacts on ocean resources—and implications on their sustainability—as a result of climate change. In general, ocean temperatures have risen over the past century and will continue to increase in the future, with impacts on climate, ocean circulation, chemistry, and ecosystems. Ocean systems absorb approximately 25 percent of anthropogenic CO_2 emissions, leading to ocean acidification (GCRP 2014). The combination of warming and acidification across water bodies has adverse effects on key habitats such as coral reefs and results in changes in distribution, abundance, and productivity of many marine species.

Globally, there has been a net migration of individuals to coastal regions, which has resulted in greater pressures on already-vulnerable coastal systems and a greater number of individuals and assets exposed to climate impacts. Transportation, energy, and water infrastructure are increasingly vulnerable to higher sea levels, storm surges, flooding, and erosion. Economic activity dependent on ports, tourism, and fisheries faces disruption due to climate-related hazards. The net global benefit of protecting

against coastal flooding and land loss is larger than the cost of inaction; the cost of adaptation will vary greatly from region to region (IPCC 2014b).

5.5.2.3.2 Observations and Projections of Climate Impacts

Anthropogenic Pressures

Climate change impacts on sea-level rise and ocean temperatures could affect large coastal populations. Approximately 600 million people live in the Low Elevation Coastal Zone (IPCC 2014b citing McGranahan et al. 2007), with approximately 270 million people exposed to the 1-in-100 year extreme sea level (Jongman et al. 2012). Globally, there has been a net migration to coastal areas, largely in flood- and cyclone-prone regions (IPCC 2014b citing de Sherbinin et al. 2012). The five nations with the highest exposure to climate coastal impacts are Bangladesh, China, Vietnam, India, and Indonesia (IPCC 2014b citing McGranahan et al. 2007 and Bollman et al. 2010, Jongman et al. 2012). Without adaptation, hundreds of millions of people will be displaced due to flooding and land loss by the year 2100, with the majority from east, southeast, and south Asia (Jongman et al. 2012).

In the United States, 120 million Americans live in counties that either border the ocean or the Great Lakes and/or are located within a 100-year coastal floodplain (GCRP 2014 citing Cooley et al. 2012). By 2100, this population is expected to increase to 131 million people, with significant numbers arriving in high-hazard zones (GCRP 2014 citing EPA 2010). These communities are at risk for episodic localized flooding associated with storm surge and coastal flooding from sea-level rise. Those at risk include a substantial number of individuals in a *high social vulnerability* category, with less economic or social mobility and are less likely to be insured (GCRP 2014). For example, in California, approximately 18 percent of those exposed to high risk will fall into a *high social vulnerability* category with less ability to adapt (GCRP 2014 citing Cooley et al. 2012).

Changes in precipitation patterns have complex impacts on coastal areas. Areas with increased precipitation will see heavier runoff from inland areas and an increased risk of extreme runoff and flooding while areas with decreased precipitation will see an increase in drought and a decrease in freshwater inflows (GCRP 2014). Over the past 3 decades, there has been an overall increase in storm activity, frequency, and intensity near the northeast and northwest coastlines (GCRP 2014 citing Vose et al. 2012). Extreme storms can erode or remove sand dunes and other land elevations, exposing them to inundation and further change (GCRP 2014).

Coastal energy, water, and transportation infrastructure are highly sensitive to higher sea levels, storm surges, inland flooding, erosion, and other climate-related changes (GCRP 2014, IPCC 2014b citing Handmer et al. 2012, Horton et al. 2010, Hanson and Nicholls 2012, and Aerts et al. 2013). The unique characteristics of coastal infrastructure increase its vulnerability and have the potential to alter coastal life and disrupt coast-dependent economic activities (GCRP 2014). Many coastal roads and bridges are already affected during storm events and extreme high tides (GCRP 2014 citing California King Tides Initiative 2012). Severe storms have been particularly disruptive to transport and power and water supplies (IPCC 2014b citing USCCSP 2008, Horton et al. 2010, and Jacob et al. 2007). Weather-related disruptions to port activities can impact multiple segments of supply chains (IPCC 2014b citing Becker et al. 2012, 2013) and hurricanes and flooding of underground infrastructure can have long-term effects (IPCC 2014b citing Chisolm and Matthews 2012).

Ecological Changes

Rising water temperatures and other climate-driven changes (e.g., salinity, acidification, and altered river flows) will impact the survival, reproduction, and health of coastal plants and animals (GCRP 2014).

Shifts in the distribution of species and ranges, changes in species interactions, and reduced biodiversity cause fundamental changes in ecosystems and can adversely impact economic activities such as fishing (GCRP 2014). Species with narrow physiological tolerance to change, low genetic diversity, specific resource requirements, or weak competitive abilities will be particularly vulnerable to climate change (GCRP 2014 citing Dawson et al. 2011 and Feder 2010).

Studies indicate that 75 percent of the world's coral reefs are threatened due to climate change and localized stressors (GCRP 2014 citing Burke et al. 2011, Dudgeon et al. 2010, Hoegh-Guldburg et al. 2007, Frieler et al. 2013, and Hughes et al. 2010). A third of reef-building corals are listed as vulnerable, endangered, or critically endangered (GCRP 2014 citing Carpenter et al. 2008) and the National Oceanic and Atmospheric Administration is proposing to list 66 species of coral under the Endangered Species Act (GCRP 2014 citing Brainard et al. 2011 and NMFS 2012). In the United States, warming waters have driven eelgrass in the Chesapeake Bay and black abalone in California to the edge of extinction (GCRP 2014 citing Moor et al. 2008, Moor et al. 2012, Altstart et al. 1996, and Neumann et al. 2010). Fisheries productivity is projected to decline in the contiguous United States and increase in parts of Alaska (GCRP 2014 citing Cheung et al. 2009). The potential for coastal ecosystems to pass a "tipping point" threshold is of particular concern as these changes can be irreversible (GCRP 2014 citing Hoegh-Guldberg and Bruno 2010).

Sea Level

There is strong evidence that temperature increases have caused a rise in global sea level during the 20th century (GCRP 2014 citing Parris et al. 2012). The change in sea level is attributed to thermal expansion of ocean water, thawing of permafrost, and the melting of mountain glaciers, ice caps, and land ice. Sea-level rise was found to be non-uniform around the world, which might result from variations in thermal expansion; exchanges of water, ocean, and atmospheric circulation; and geologic processes (IPCC 2014b). Higher sea levels cause greater coastal erosion; changes in sediment transport and tidal flows; landward migration of barrier shorelines; fragmentation of islands; and saltwater intrusion into aquifers, croplands, and estuaries (GCRP 2014 citing Burkett and Davidson 2012, CCSP 2009, IPCC 2007, Irish et al. 2010, and Rotzoll and Fletcher 2013, Nicholls and Cazenave 2010). Furthermore, regional sea-level rise has contributed to amplified storm-surge impacts and an increased risk of flooding in certain low-lying areas, affecting the growing populations along the coasts (GCRP 2014). In many locations, the cost of rebuilding beaches and dunes is increasing as supplies near project sites are depleted (IPCC 2014b).

Tebaldi et al. (2012) (as cited in IPCC 2014b) estimated projected changes in coastal flooding during storm events at 55 locations along the U.S. coastline. The study used a semi-empirical approach (i.e., a relationship derived between observed global annual temperature and observed annual sea level, driven by projections of global annual temperature) to estimate a 0.32-meter (1.05-foot) global sea-level rise by 2050. The authors translated the global sea-level rise projection to projections of local sea-level rise at each of the coastal locations, and then used the projections of local sea-level rise to estimate the change in storm-driven water heights for historic events for a number of return periods. This study projected that most of the 55 locations will experience an increase in the frequency of extreme storm-driven waters. For a third of the locations, flooding associated with a once a century event (i.e., a storm with a 1 percent probability of occurrence in any given year) will occur more often, and statistically become a decade event (i.e., a storm with a 10 percent probability of occurrence in any given year).

Sea-level rise is expected to be one of the most damaging effects of climate change. In the 21st century, global mean sea level is expected to exceed the observed rate for the period of 1971 to 2010 of 2.0 millimeters (0.8 inch) per year (IPCC 2014b). Sea-level rise will expand floodplain areas and place more

individuals in high-hazard zones; coastal communities could face increased flooding and erosion. Coastal systems and low-lying areas are expected to increasingly experience submergence, flooding, and erosion of beaches, sand dunes, and cliffs (IPCC 2014b). Coastal squeeze, which occurs when an eroding shoreline approaches hard, immobile structures, is expected to accelerate with a rising sea level.

Displacement of coastal populations due to sea-level rise, flooding, and increased intensity and frequency of storms remains a concern. Furthermore, the loss or degradation of coastal ecosystems has a direct impact on societies that depend on coastal-related goods and services such as freshwater and fisheries and has the potential to impact hundreds of millions of people.

Acidification and Hypoxia

Oceans absorb approximately 25 percent of human-caused CO_2 annually, resulting in a 30 percent increase in acidification since pre-industrial times (GCRP 2014 citing NRC 2010, Sabine et al. 2004, and Feely et al. 2009). There is very *high confidence* that coastal areas experience considerable temporal and spatial variability in seawater pH compared to the open ocean due to additional natural and human influences (IPCC 2014b). Increased CO_2 uptake in the oceans makes it more difficult for organisms to form and maintain calcium carbonate shells and skeletal structures; increases erosion and bleaching of coral reefs and their biodiversity; and reduces growth and survival of shellfish stocks globally (GCRP 2014 citing Tribollet et al. 2009, Wisshak et al. 2012, and Doney et al. 2009). Changes in ocean acidity have economic impacts on aquaculture along the coast as it decreases the production of species such as oysters, mussels, and sea urchins (GCRP 2014).

There is *high confidence* that coastal acidification will continue into the 21st century but with large, uncertain regional variation (IPCC 2014b). Acidification will have significant negative consequences for coastal ecosystems, resulting in coral bleaching and mortality, decline of temperate seagrass and kelp ecosystems, and an increase of subtropical invasive species (Hooidonk et al. 2014, IPCC 2014b). Diversity, biomass, and trophic complexity of coastal communities will decrease at future pH levels (IPCC 2014b citing Barry et al. 2011 and Kroeker et al. 2011).

Hypoxia in ocean environments is a condition under which the dissolved oxygen level in the water is low enough to be detrimental to resident aquatic species. Specifically, waters with oxygen concentrations below 60 µmoles/kg are considered hypoxic (IPCC 2014b citing Deutsch et al. 2011). Oxygen minimum zones (OMZ) have been growing over the past half-decade and are projected to continue expanding to temperate and sub-polar regions with future warming (IPCC 2014b). Research has found that the ability of marine organisms to survive in hypoxic conditions is further strained by warming ocean temperatures. Marine benthic organisms (i.e., organisms that live on or near the ocean floor) have been shown to have significantly shortened survival times when subjected to warmer hypoxic conditions, as the necessary dissolved oxygen threshold for survival increases with temperature (Vaquer-Sunyer and Duarte 2011; *see* Section 5.6 for additional information on ocean acidification).

Salinity

Ocean salinity levels can be affected by freshwater additions, ocean evaporation, and the freezing or thawing of ice caps and glaciers. Marine organisms are adapted to specific levels of ocean salinity and often become stressed by changing salinity levels. Additionally, changing ocean salinity levels affects the density of water, which in turn impacts factors such as the availability of local drinking water and, potentially, global ocean circulation patterns. Although the globally averaged salinity change is small, changes in regional basins have been significant. Salinity in ocean waters has decreased in some tropical and higher latitudes due to a higher precipitation-to-evaporation ratio and sea-ice melt (IPCC 2014b

citing Durack et al. 2012). Evaporation-dominated subtropical regions are exhibiting definite salinity increases, while regions dominated by precipitation are undergoing increasing freshening in response to intensification of the hydrological cycle. These effects are amplified in regions that are experiencing increasing precipitation or evaporation. Findings through surface water analyses of the Atlantic Ocean show increased salinity, while the Pacific Ocean demonstrates decreased salinity, and the Indian Ocean has observed minimal changes (Durack and Wijffels 2010). However, these are general trends and vary somewhat, both across the large bodies of water and below thermocline[42] levels. Changes in salinity are likely to affect ocean density, structure, and circulation in the future. Ocean circulation is primarily driven by changes in seawater density, which is driven by temperature and salinity. Colder and more saline water (such as the waters found in the North Atlantic) is denser and sinks into ocean depths, resulting in downwelling.[43] Projected changes in salinity will likely influence ocean circulations, especially at higher latitudes where salinity is a more active variable.

Productivity

Net primary production (NPP) refers to the net flux of carbon from the atmosphere into organic matter over a given time period.[44] Ocean systems provide approximately half of global NPP. NPP is influenced by physical and chemical gradients at the water surface, light, and nutrient availability. A changing climate alters the mixed layer depth, cloudiness, and sea-ice extent, thus altering NPP. Open-ocean NPP is projected to reduce globally, with the magnitude of the reduction varying depending on projection scenario (IPCC 2014b). Satellite observations of ocean chlorophyll indicate that global ocean annual primary production has declined by more than 6 percent since the early 1980s, with almost 70 percent of this decline occurring in the high latitudes (Brander 2010 citing Gregg et al. 2003). Chlorophyll is a constituent of photosynthetic organisms such as algae and is an indicator of ecosystem productivity that is visible from satellite observations of Earth's oceans. Lower chlorophyll concentrations at warmer sea surface temperatures in nutrient-poor waters indicate declining phytoplankton stocks, particularly in the North and South Pacific and North and South Atlantic (IPCC 2014b). According to research by Arrigo and van Dijken, longer growing seasons and more sea-ice free days could have increased NPP in Arctic waters in the past decade and are expected to increase through the next century (IPCC 2014b citing Arrigo and van Dijken 2011).

In the past, ocean productivity has generally adjusted to natural variations in ocean climate. However, present climatic trends are expected to continue outside the bounds of previous variability at a much faster rate.

5.5.2.3.3 Adaptation

Projected impacts from climate change will require some level of adaptation to address impacts on affected marine, coastal, and low-lying regions. Adaptation for sea-level rise falls mostly into three major categories: retreat, accommodate, and protect (IPCC 2014b citing Nicholls 2011), which are widely used around the world (IPCC 2014b citing Boateng 2010 and Linham and Nicholls 2012).

[42] A thermocline is a transitional layer between water at the surface (also known as the mixed layer) and deep water. The definition of these layers is based on water temperature. In the thermodine, the temperature decreases rapidly from the mixed layer to the deep water (NOAA 2012).

[43] Downwelling, or the sinking of water from the surface, is an important part of the ocean circulation process that brings oxygen-rich water to the deep sea.

[44] Net primary production is estimated as the amount of carbon synthesized via photosynthesis minus the amount of carbon lost via cellular respiration.

Retreating allows the impacts of sea-level rise to occur unobstructed, while inhabitants pull back from inundated coastlines. Accommodation is achieved by increasing the flexibility of infrastructure and adjusting the use of coastal zones where impact is most likely (IPCC 2014b). Protection is the creation of barriers against sea intrusion through the use of replenished beaches and seawalls. Ecosystem-based protection strategies, which include the protection and restoration of relevant coastal natural systems (IPCC 2014b citing Schmitt et al. 2013), oyster reefs (IPCC 2014b citing Beck et al. 2011), and salt marshes (IPCC 2014b citing Barbier et al. 2011), are increasingly attracting attention (IPCC 2014b citing Munroe et al. 2011).

For the 21st century, the benefits of adaptation initiatives for coastal and ocean systems are larger than the social and economic costs of inaction (IPCC 2014b). The cost of inaction is estimated to be 4–10 times greater than the costs associated with preventative hazard mitigation (GCRP 2014 citing Neumann et al. 2010 and Multihazard Mitigation Council 2005), but the costs vary strongly between and within regions and countries (IPCC 2014b). Low-lying developing countries such as Bangladesh or Vietnam and small island states will face higher adaptation costs that could amount to several percentage points of GDP (IPCC 2014b).

Progress has been made in the United States in the past few years in terms of coastal adaptation, science, and practice, but most coastal managers are still building their capacities for adaptation (GCRP 2014 citing NRC 2010, Carrier et al. 2012, Moser 2009, and Poulter et al. 2009). Some examples of coastal adaptation include (1) integrating natural landscape features with built infrastructure (green and gray infrastructure[45]) to reduce storm water runoff and wave attack; (2) constructing seawalls around wastewater treatment plants and pump stations; (3) pumping effluent to higher elevations as sea levels rise; (4) pumping freshwater into coastal aquifers to mitigate salt water infiltration; (5) developing flood-proof infrastructure; (6) relocation of large coastal infrastructure away from the coast; and (6) relocation of communities away from high-hazard areas (GCRP 2014). Some examples of ocean adaptation include (1) reducing overfishing, establishing protected areas, and conserving habitat to increase resilience; (2) culturing acid-resistant strains of shellfish; (3) oyster reef and mangrove restoration; (4) coral reef restoration and protection; and (5) developing alternative livelihood options for marine food-producing sectors (GCRP 2014).

5.5.2.4 Food, Fiber, and Forest Products

Climate change is affecting food, feed, fiber, forest products, and food security around the world. Increases in atmospheric CO_2, rising temperatures, and altered precipitation patterns will affect both agricultural and forest systems (Walthall et al. 2012, GCRP 2014, IPCC 2014). For example, climate change is predicted to affect a wide range of ecosystem processes, including maintenance of soil quality and regulation of water quality and quantity (GCRP 2014). Changes in these and other ecosystem services will exacerbate stresses on agricultural plants and animals and forests (Walthall et al. 2012, GCRP 2014). Additionally, increased frequency and intensity of extreme weather events is expected to negatively influence agricultural and forest productivity and increase the vulnerability of agriculture and forests to climate risks (Walthall et al. 2012, GCRP 2014, IPCC 2014). Overall projections for crop and livestock production systems indicate that climate change effects over the next 25 years will be mixed (IPCC 2014, Walthall et al. 2012), although most predictions for climate change effects on crop yields by 2050 are negative (Nelson et al. 2014, IPCC 2014, Müller and Robertson 2014). Forests are becoming

[45] Green infrastructure refers to sustainable pollution reducing practices that also provide other ecosystem services (e.g., permeable pavements, green roofs). Gray infrastructure refers to traditional practices for stormwater management and wastewater treatment, such as pipes and sewers.

more vulnerable to ecosystem changes and tree mortality due to fire, insect infestation, drought, disease outbreaks, and extreme weather events (Joyce et al. 2014, IPCC 2014). Additionally, climate change and current trends in land use and forest management are expected to decrease the current forest CO_2 uptake rate (Joyce et al. 2014).

Over the past 150 years, landowners and forest managers have demonstrated an impressive capacity to adapt to a diversity of growing conditions amid dynamic social and economic changes (Walthall et al. 2012, Joyce et al. 2014). However, current adaptation technologies are predicted to be insufficient to buffer future impacts of climate change resulting in significant impacts on domestic producers, consumers, or both (GCRP 2014). Forest management responses to climate change will be influenced by the changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and climate change policy. Agricultural plants and animals and managed forests will strongly depend on the responses taken by humans to moderate the effects of climate change (Walthall et al. 2012, Joyce et al. 2014).

5.5.2.4.1 Summary

Climate disruptions to agricultural production have increased over the past 40 years and are projected to further increase over the next 25 years. Climate change is also increasing tree mortality and forest ecosystem vulnerability due to fire, insect infestations, drought, disease outbreaks, and extreme weather events. As critical thresholds are already being exceeded, increased incidences of weather extremes will result in larger productivity losses in crops, livestock, and forests. Increases in temperatures and changes in precipitation patterns are changing the nutritional quality of pastures and grazelands, stressing animals and decreasing livestock productivity. Increases in ocean temperatures are resulting in many marine fish species migrating to deeper and/or colder water and are adding additional stress to already strained coral reefs.

Many regions will experience declines in production of crops, livestock, and forests due to increases in weeds, diseases, insect pests, and other climate change induced stresses, although currently there are no models to accurately predict these impacts. Climate change effects on food, including yields, food processing, storage, and transportation, will affect food prices and food security globally, with impacts likely having the greatest effects on individuals in developing countries.

5.5.2.4.2 Observations and Projections of Climate Impacts

<u>Agriculture and Croplands</u>

As agriculture is central to the livelihoods of many people, especially in developing countries, climate change poses a significant challenge to the agricultural community globally (IPCC 2014). This is due to agriculture's dependence on climate and the complex role of agriculture in social and economic systems at rural and national levels (GCRP 2014). As plant responses to climate change are dependent on complex interactions between CO_2, temperature, solar radiation, and precipitation, climate change is currently having both positive and negative impacts on crop and food production, although negative impacts are more common in most regions (IPCC 2014). Future impacts are predicted to be both positive and negative (GCRP 2014), although the majority of models indicate that yields of major crops will be negatively affected by climate change (Nelson et al. 2014, Müller and Robertson 2014). Specific climate impacts on agriculture will vary based on the species, location, timing, and current productivity of agricultural systems (including crops, livestock, and fish) at local, national, and global scales (GCRP 2014).

Climate change is predicted to cause multiple abiotic ("nonliving") stressors (such as temperature, moisture, extreme weather events), and biotic ("living") stressors (such as disease, pathogens, weeds and insects) on crop production. Changes in precipitation patterns are predicted to result in changes in timing of rains (which can affect when to plant crops), intensity of rains, floods, and droughts (Thornton et al. 2014, IPCC 2014, GCRP 2014). Temperature changes (including mean temperature and temperature extremes) affect multiple plant processes including growth, production of seeds, fruits and fibers, and yield (IPCC 2014, GCRP 2014). Additionally, weather extremes including heat, severe drought, and heavy precipitation are expected to increase (GCRP 2014 citing Peterson et al. 2012) and studies suggest increased average temperatures and drier conditions will amplify future drought severity and temperature extremes (GCRP 2014 citing IPCC 2007, Alexander et al. 2006, and Karl et al. 2012).

Crop yields are both positively and negatively impacted by changes in temperature, depending on the crop species as well as the timing and amount of temperature change (including both mean and extreme temperatures). All plants have specific temperature tolerances, and as temperatures increase above these tolerances, crop production areas could have to shift or plant growth and yields will likely be reduced (GCRP 2014, IPCC 2014). For example, wheat plants exposed to high temperatures have a reduced time to maturation (IPCC 2014 citing Iqbal et al. 2009), reduced grain setting (if high temperatures occur during flowering) (IPCC 2014 citing Moriondo et al. 2011), and experience increased water stress throughout the growing season (IPCC 2014 citing Lobell et al. 2012). Temperature is of particular importance to crop production during reproduction (including pollination) and fruit/grain setting. Exposure to high nighttime and overall temperatures during this period have been shown to result in lower productivity and quality, greatly reduced crop yields, and increased risk of total crop failure (GCRP 2014 citing Walthall et al. 2012, GCRP 2014, Teixeira et al. 2013). For example, nighttime temperatures of 32°C (89.6°F) result in a 90 percent reduction of rice yields compared to night time temperatures of 27°C (80.6°F) (Thornton et al. 2014 citing Mohammed and Tarpley 2009). In particular, temperate and sub-tropical agricultural areas are predicted to experience substantial crop yield losses due to extreme temperature episodes (Teixeira et al. 2014). Perennial specialty crops with winter chilling requirements (including fruit and nut trees and grape vines) also show reduced yields if their chilling requirements are not met (GCRP 2014 citing Luedeling 2012).

Precipitation extremes are predicted to become increasingly intense, and rainfall variability is expected to increase resulting in an increase of floods and droughts (GCRP 2014). Increased frequency of extreme precipitation events is expected to reduce yields by exacerbating soil degradation and loss (GCRP 2014). Increased rainfall intensity will escalate soil erosion (GCRP 2014 citing Kunkel et al. 2013, Mass et al. 2011) as will reduced crop biomass resulting in fewer crop residues available to stabilize soil surfaces during winter months (GCRP 2014 citing O'Neal et al. 2005 and Wischmeier et al. 1978). Shifting precipitation patterns will change timing of planting and growing seasons as well as contribute to dry spells and sustained droughts that will likely reduce yields (Thornton et al. 2014).

Climate change has the potential to increase the impacts of disease, pathogens, insects, and weed species in agricultural crops. Currently, weed growth is the largest biotic cause of crop yield loss globally (34 percent), followed by insects (18 percent) then disease (16 percent) (GCRP 2014 citing Oerke et al. 2006). While elevated CO_2 levels and temperatures have been shown to increase both crop and weed growth, several weed species have been shown to outcompete crops under these conditions, likely resulting in further reduced crop yields (GCRP 2014 citing Ziska 2001, 2003, 2010). As temperatures and

CO_2 levels continue to rise, costs for weed control[46]—including herbicides—are expected to increase (Ziska 2014, GCRP 2014 citing Koleva et al. 2009).

In terms of insects and diseases, earlier spring and warmer winter conditions are expected to increase the survival and proliferation of disease-causing agents and parasites (GCRP 2014). Warmer winter temperatures increase insect winter survival rates, and higher summer temperatures increase reproductive rates, allowing for more insect generations in a year (GCRP 2014 citing Porter et al. 1991). Furthermore, changing climate and trade patterns are expected to increase the risk and sources of invasive species (GCRP 2014 citing Bradley et al. 2012). However, due to the lack of models, it is not currently possible to quantitatively estimate climate change induced impacts of diseases, pathogens, insects, or weed species on agricultural plants (GCRP 2014, Nelson et al. 2014).

Interestingly, increases in temperature, CO_2 concentration and solar radiation have been predicted to increase growth rates of some plants (GCRP 2014). However, effects vary by plant species and are also dependent on other factors, such as adequate water and soil nutrients. For example, if soil nutrients and water are not sufficient to support increased growth rates, smaller plants with lower production values will be produced (GCRP 2014). Additionally, weed growth is also predicted to increase under these conditions, further dampening any potential yield gains from increased growth rates (GCRP 2014).

Overall, climate change is predicted to have mixed, although mostly negative, effects on crop yields, depending on the crop species and location. Studies comparing projections for different regions or crops have identified South Asia and Southern Africa as two regions that are likely to suffer the most negative impacts on important crops (IPCC 2014 citing Lobell et al. 2008) with Knox et al. (2012) estimating an expected 8 percent negative yield in both areas by 2050 averaged over multiple crops (IPCC 2014 citing Knox et al. 2012). Müller and Robertson (2014) used two agricultural models, Decision Support System for Agrotechnology Transfer (DSSAT)[47] and Lund-Potsdam-Jena managed Land (LPJmL)[48], under the high-end emissions scenario (RCP8.5) and two general circulation models, HadGEM2- and IPSL-CM5ALR, to determine yield projections in 2050. Projections were conducted for the five crops that are simulated by both models: wheat, maize, rice, soybean, and groundnut. Under all analyzed scenarios, with the exception of temperature limited mountains and high latitude areas, climate change led to decreases in agricultural productivity, with crop yields decreasing by 9.9 to 37.6 percent on a global scale by 2050 as compared to 2000 (Müller and Robertson 2014). In general, climate impacts on yields had similar distributions between crop models and climate scenarios, but spatial patterns of impacts differed significantly with some areas showing increased yield and others showing decreased yield (Müller and Robertson 2014). For example, rainfed wheat productivity showed increases in the eastern United States (including Michigan and Ohio), Estonia, Latvia, and the western regions of Russia using the DSSAT model, but the same areas showed decreases in productivity using the LPJmL model (Müller and Robertson 2014). Using the same combination of agricultural and general circulation models and the same emissions scenario (RCP8.5), Nelson et al. (2014) determined the annual effects of climate change on the yields of the major commodity groups (coarse grains, rice, oil seeds, sugar, and wheat) in five countries (Brazil, Canada, China, India, and the United States) compared to no climate

[46] Currently approximately $11 billion a year.

[47] DSSAT is a framework for crop models that uses daily weather information and a soil module that keeps track of hydrology and nutrient cycles based on consideration of a variety of soil characteristics. Other models were used to input specifics for crops: CERES models for rice (*Oryza sativa*), wheat (*Triticum* spp.), and maize (*Zea mays*) and the CROPGRO models for soybeans (*Glycine max*), and groundnuts (*Arachis hypogaea*).

[48] LPJmL is a global dynamic vegetation, hydrology, and crop growth model that simulates yields of the 12 most important crops globally: temperate and tropical cereals, roots and tubers, maize, rice, pulses, soybeans, oil crops and sugarcane.

change from 2005 to 2050. The climate effects are almost uniformly negative, with the largest decreases in yield most commonly found in crops grown in India and Brazil (Nelson et al. 2014). Sugar was the only crop showing moderate yield increases in all countries (except India) under multiple model combinations (Nelson et al. 2014).

Livestock

Although there is not as much work published on livestock production, climate change is predicted to have multiple effects on animal production. These effects include animal nutrition (production, availability, and price of feed-grains as well as production and quality of pasture and forage crops) and overall animal wellbeing (animal health, growth, and reproduction and distribution of animal diseases and pests) (GCRP 2014 citing Rotter et al. 1999). Overall, current predictions are that climate change will negatively impact livestock on almost all the continents (IPCC 2014).

In many livestock systems, one of the major climate change impacts on animals is changes in feed quantity and quality (Thornton et al. 2014). In particular climate change is predicted to impact pastures and animal feed through changes in temperature and rainfall (including variability and amount); CO_2 concentrations; extreme weather events; and changes in diseases, pathogens, weeds, and insect species (IPCC 2014, Thornton et al. 2014). For example, in North America, warming is predicted to both lengthen the growing season and decrease forage quality with additional variation due to changes in rainfall patterns (IPCC 2014 citing Craine et al. 2010 and Izaurralde et al. 2011, GCRP 2011). Species composition in both temperate and tropical grassland is a key determinate of livestock productivity. Climate change is predicted to impact the dynamics and balance of grassland species, including plant competition, perennial growth habits, and seasonal productivity, which could also affect livestock productivity (Thornton et al. 2014, IPCC 2014). Given the complex interactions between climate and non-climate drivers on pastures and forageland, it is currently difficult to predict long-term impacts of climate change on these lands (IPCC 2014, Thornton et al. 2014).

In terms of direct impacts on animals, there is high confidence that high temperatures will have negative effects on animal feeding and growth rates (IPCC 2014 citing Andre et al. 2011, Renaudeau et al. 2011). In general, livestock have comfort zones between 10˚C (50˚F) and 30˚C (86˚F) (Thornton et al. 2014) and can tolerate deviations in core body temperatures of up to 4˚F. Deviations in excess of 4 to 5°F cause significant reductions in productive performance while deviations in the range of 9 to 12°F often result in death (GCRP 2014 citing Gaughan et al. 2009). For example, when exposed to temperatures above 30°C (86˚F) animals reduce their feed intake 3 to 5 percent per additional degree of temperature (Thornton et al. 2014 citing NRC 1981), which can result in reduced rates of meat, milk, and egg production (GCRP 2014 citing Mader 2012). While livestock production systems that provide partial or total shelter can reduce heat stress, management and energy costs associated with such structures are predicted to increase with increasing temperatures and decreasing water availability (GCRP 2014). Changes in rainfall distribution are also expected to exacerbate existing challenges of supplying adequate water to livestock (IPCC 2014).

Changes in climate variability, including rainfall distribution, regional warming patterns, and extreme weather events are predicted to impact the prevalence and distribution of livestock host and pathogen systems (GCRP 2014, Thornton et al. 2014, IPCC 2014). For example, disease outbreaks of Rift Valley fever and blue-tongue in east Africa have followed combinations of high rainfall preceded by drought (Thornton et al. 2014 citing Baylis and Githeko 2006). Rift Valley fever could continue to spread northward due to rising temperatures and the increased winter survival of pathogens and hosts (IPCC 2014 citing Lancelot et al. 2008). Other diseases also sensitive to moisture and temperature could also spread under changing climatic conditions. These include anthrax, blackleg, and hemorrhagic

septicemia, which cause increased incidence of ketosis, mastitis, and lameness in dairy cows (GCRP 2014 citing Gaughan et al. 2009 and Baylis et al. 2006).

Fisheries

Climate change is affecting aquatic ecosystems, including marine and freshwater fisheries (IPCC 2014, Groffman et al. 2014). Fisheries are important contributors to food security and 90 percent of individuals involved in the sector are employed in small-scale fisheries, many of whom are in developing countries (IPCC 2014 citing Cochrane et al. 2011). Climate change impacts on marine fisheries have primarily been linked to increasing temperatures (including both mean and extreme temperatures), but are also affected by increasing CO_2 concentrations (IPCC 2014). Fisheries can also be impacted by overfishing, pollution, land or habitat change, and climate variability, making it difficult to determine which effects are directly attributable to climate change and which are due to other factors (IPCC 2014).

Climate change induced increases in ocean temperatures have resulted in shifts of many fish species to cooler and/or deeper water (IPCC 2014). For example, current studies of the northeast Atlantic have shown that rising sea temperatures are resulting in a poleward shift in the distribution of fish, increasing abundance to the north and decreasing abundance to the south (IPCC 2014 citing Perry et al. 2005, Brander 2007, Cheung et al. 2010, and Cheung et al. 2013). Similar poleward trends have been seen off southeast Australia (IPCC 2014 citing Last et al. 2011). These shifts are impacting marine fisheries by changing the species composition found in marine capture fisheries where warmer water species are increasing at higher latitudes and subtropical species are decreasing in the tropics (IPCC 2014). Barange et al. (2014) used a single general circulation model (Institute Pierre Simon Laplace Global Climate Model (IPSL-CM4)) with the A1B climate scenario to determine mean outputs of 67 marine national exclusive economic zones (EEZs) (which yield approximately 60 percent of global fish catches) from the present to 2050. The models predicted an average increase in the global fisheries production potential of 3.4 percent by 2050, with ecosystems in higher latitudes experiencing production increases and those in lower latitudes experiencing decreases (Barange et al. 2014). For example, the Nordic Sea, the Gulf of Guinea, and the Kuroshio Current region are predicted to have the largest average increase in fish catch potential (29.3, 29.3 and 21.3 percent respectively), while the Canary Current and the northwestern American shelf are predicted to have the largest average decreases (-14.6 and -13.2 percent, respectively) (Barange et al. 2014). Reductions in catch potential are predicted to have the greatest negative impacts for countries most nutritionally and economically dependent on fisheries, including those in south and southeast Asia, southwest Africa, Peru, and some tropical small-island developing states (Barange et al. 2014, IPCC 2014).

Warmer temperatures and temperature fluxes negatively affect coral reefs and reef ecosystems. Coral reef ecosystems provide food and other resources to more than 500 million people annually at an estimated value of US$5 billion or more (IPCC 2014 citing Hoegh-Guldberg 2011 and Munday et al. 2008). Currently more than 60 percent of coral reefs are considered to be under immediate threat of danger due to local threats (such as pollution and overfishing) and projected increases in sea temperature and heat stress will very likely irreversibly degrade reefs even further (IPCC 2014). Coral bleaching and other reef challenges have also resulted in a loss of fish species that feed on coral-associated invertebrates, and fish and invertebrate species associated with reefs in many important tropical coastal fisheries are very likely to be reduced (IPCC 2014).

There are fewer data available on climate change impacts on fisheries in freshwater systems, with current changes and predictions showing mixed results (IPCC 2014, Comte et al. 2013a). Comte et al. (2013) conducted a meta-analysis of published literature reporting observed and predicted effects of climate change on the distribution of freshwater fish. Despite large data gaps and a geographic bias

towards the northern hemisphere and the temperate regions of the Nearctic and Palaearctic realms, the authors found that freshwater species could be severely affected by current and future climate change resulting in mixed effects. For example, temperature increases are estimated to cause a loss of 11 to 22 percent of suitable stream length for bull trout in central Idaho, while resulting in a gain of small patches of habitat for rainbow trout (Comte et al. 2013b citing Isaak et al. 2010). Cold- and cool-freshwater fish are expected to be impacted by warming temperatures, which could result in local extinctions, contractions, or shifts in habitat, whereas warm-water species could benefit from warmer water, depending on the species, the local habitat, and non-climate stressors (Comte et al. 2013a). Similar to marine fisheries, changes in productivity in freshwater fisheries can be impacted by both climate and non-climate stressors, making it difficult to determine which effects are directly attributable to climate change (IPCC 2014). For example, studies on Lake Tanganyika in east Africa have conflicting results, with one study showing a 30 percent reduction in lake productivity due to climate change (IPCC 2014 citing O'Reilly et al. 2003) and another indicating that the reduction is due to non-climate related factors, such as overfishing (IPCC 2014 citing Sarvala et al. 2006). Accurate predictions of future effects of climate change on freshwater fisheries are currently limited by incomplete data and limited modeling capabilities (Comte et al. 2013a, IPCC 2014).

Forests

Forests and climate change have strong interactions with each other. Air temperature, solar radiation, rainfall, and atmospheric CO_2 all can drive forest productivity, and forests control climate through carbon sequestration and release and evapotranspiration (i.e., the evaporation of water from soil and land, and transpiration from vegetation) (IPCC 2014 citing Arneth et al. 2010, Pan et al. 2011, and Pielke et al. 2011). Currently, tree mortality is increasing globally due in part to high temperatures and drought (IPCC 2014). There is *medium confidence* that this increased mortality and forest dieback (high mortality rates at a regional scale) will continue in many regions around the globe through 2100 (IPCC 2014). For example, in western North America, long-term increasing tree mortality in boreal and temperate forests has been associated with high temperatures and drought (IPCC 2014 citing van Mantgem et al. 2009 and Peng et al. 2011), and increased tree mortality has been detected after drought in multiple tropical forests and Europe (IPCC citing Kraft et al. 2010, Phillips et al. 2010, and Carnicer et al. 2011). Forest dieback has been observed in multiple types of forests in western North America, Australia, and southern Europe (IPCC citing Raffa et al. 2008, Carnicer et al. 2011, and Anderegg et al. 2013) and in some cases in combination with insect infestations (IPCC 2014 citing Hogg et al. 2008, Michaelian et al. 2011, and Raffa et al. 2008). However, due to the lack of models and limited long-term studies, projections of global tree mortality are currently highly uncertain (IPCC 2014 citing McDowell et al. 2011).

Other climate change induced direct and indirect effects, such as changes in the distribution and abundance of insects and pathogens, fire, changes in precipitation patterns, invasive species, and extreme weather events (e.g., high winds, ice storms, hurricanes, and landslides) are also affecting forests (Thornton et al. 2014, IPCC 2014, GCRP 2014, IPCC 2014 citing Allen et al. 2010). Warmer winter temperatures have resulted in increased insect populations, and projected temperature increases are expected to facilitate their expansion poleward and in altitude, contributing to or causing tree mortality (IPCC 2014 citing Bentz et al. 2010). For example, the USDA Forest Service reports that approximately 81 million acres of the nation's forests are at risk of insects and diseases (Krist et al. 2014). Heat waves and drought are contributing to increased wildfires in forests and are resulting in predictions of increased fire risk. For example, in the lower 48 states of the United States, there has been an 84 percent increase in wildfires since 1990 (EPA 2014), and approximately 58 million acres of National Forest System lands are at risk of intense wildfire (Krist et al. 2014). Increased fire risk, a longer fire season, and more frequent, severe fires due to heat waves and drought are also predicted in the

Mediterranean region (IPCC 2014 citing Duguy et al. 2013). Tracking and attributing disturbance and corresponding mortality is a challenge; however, with satellite imagery severity can be mapped as a percent change in satellite-derived Disturbance Index (Joyce et al. 2014 citing Mildrexler et al. 2009).

Tree species are predicted to shift their geographic distributions to track figure climate change (Zhu et al. 2014). For example, many projections are for poleward expansions of forests into tundra regions, and species shift towards temperate plants, and there is *medium confidence* that temperate tree species are migrating poleward and to higher altitudes (IPCC 2014). To determine if shifting is already occurring, Zhu et al. (2014) modeled juvenile and adults from 65 tree species across climates in the eastern U.S. using species abundance data from the Forest Inventory and Analysis (FIA) program and climate data from the Parameter-elevation Regression on Independent Slopes Model (PRISM). The authors found that juvenile tree distribution did not appear to follow a northern migration pattern, but it instead followed patterns of rapid turnover in warm and wet climates (likely due to longer growing seasons resulting in faster maturation and rapid thinning) (Zhu et al. 2014). The authors concluded that at biogeographic scales, U.S. forests are responding to climate change with faster turnover rates, but not yet northward migration (Zhu et al. 2014).

Reduced Sequestration

While there is currently *high confidence* that forests are serving as a net carbon sink globally, it is unclear if this trend will continue (IPCC 2014). Excess carbon sequestered by intact and regrowing forests appears to have stabilized in recent years (IPCC 2014 citing Canadell et al. 2007 and Pan et al. 2011). Warming, changes in precipitation, pest outbreaks, and current social trends in land use and forest management are projected to impact the rate of CO_2 uptake in the future (Joyce et al. 2014, IPCC 2014 citing Allen et al. 2010), making it difficult to predict whether forests will continue to serve as net carbon sinks in the long term (IPCC 2014).

Food Security and Risks to Vulnerable Populations

Climate change impacts on food security and food systems are predicted to be widespread, complex, geographically and temporally variable, and greatly influenced by socioeconomic conditions (IPCC 2014 citing Vermeulen et al. 2012). Food security comprises four key components: availability, stability, access, and utilization of food (GCRP 2014 citing FAO 2001), all of which are closely tied to poverty (IPCC 2014). Food security is affected by variety of supply and demand-side pressures, including economic conditions, globalization of markets, safety and quality of food, land use change, demographic change, disease, and poverty (GCRP 2014 citing Ericksen et al. 2009 and Misselhorn et al. 2012). While there is a limited quantitative understanding of how nonproduction aspects of food security will be affected by climate change, it is likely that they will also be affected by climate change (IPCC 2014).

Projected rising temperatures, changing weather patterns, and increases in the frequency of extreme weather events will affect food security by potentially altering agricultural yields, post-harvest processing, food and crop storage, transportation, retailing, and food prices (GCRP 2014). For example, 10 economic models (using 2 agricultural models, 2 general circulation models, and the high-end emissions scenario [RCP8.5] as their basis) currently predict that by 2050, climate change will increase the aggregate price of the 5 major commodity groups (coarse grains, rice, oil seeds, sugar, and wheat) by 3 to 78.9 percent (Nelson et al. 2014). Similarly, von Lampe et al. (2014) used the identical suite of 10 economic models (using 2 agricultural models, 2 general circulation models, and the high end-emissions scenario [RCP8.5]) to model food security and food prices in 2050 under alternate socio-economic, climate change, and bioenergy scenarios. While each of the models produced different results, the authors found that in general, climate change will result in reduced per capita calorie availability around

the world in 2050 compared to scenarios with no climate change, with the largest decline in India at 11 percent (von Lampe et al. 2014). Production of biofuels was found to have a much smaller impact on agricultural prices and food security than climate change (von Lampe et al. 2014).

Of those globally who do not have enough food to eat, the vast majority of undernourished people live in developing countries (IPCC 2014). While estimates vary as to incidence of food insecurity, sub-Saharan Africa had the highest proportion of food insecure people (39 to 59 percent depending on the study) (IPCC 2014 citing Smith et al. 2006 and FAO et al. 2012) whereas south Asia has the highest numbers of food insecure with approximately 300 million undernourished people (IPCC 2014 citing FAO et al. 2012). The United States is also experiencing food insecurity; in 2011, 14.9 percent of U.S. households did not have secure food supplies at some point during the year, and 5.7 percent of U.S. households experienced very low food security (GCRP 2014 citing Coleman-Jensen et al. 2012). As most countries import at least some of their domestic food consumed, climate change has the potential to affect not just food production but also the amount of food countries import and export. For example, using 10 economic models (described in more detail above), von Lampe et al. (2014) found that climate change could result in substantially higher net food imports in 2050 (assuming no changes in trade policies), with some regions being more affected than others, as compared to scenarios with no climate change. For example, in 9 out of 10 models, India was shown to increase its net imports of the five major commodity groups (described above), whereas most models showed Canada and Brazil increasing net exports of these groups (von Lampe et al. 2014).

5.5.2.4.3 Adaptation

Agricultural producers have always had to adapt to their environment to be economically successful. Recent changes in climate, however, threaten to outpace the current adaptation rate and create challenges for the agricultural sector and associated socioeconomic systems (GCRP 2014, IPCC 2014). Economic literature indicates that in the short term, producers will continue current adaptation practices for weather changes and shocks (e.g., by changing timing of field operations, shifts in crops grown, changing tillage/irrigation practices) (GCRP 2014 citing Antle et al. 2004). In the long-term, however, current adaptation technologies will likely prove insufficient to buffer the impacts of climate change (GCRP 2014). However, practices associated with sustainable agriculture, such as diversifying crop rotations, integrating livestock with crop production systems, improving soil quality, and minimizing off-farm flows of nutrients and pesticides can increase resiliency to climate change (GCRP 2014 citing Easterling 2010, Lin 2011, Tomich et al. 2011, and Wall and Smit 2005). For example, in California's Central Valley, an adaptation plan was adopted that includes changes to crop mix, irrigation methods, fertilizer practices, tillage practices, and land management. This plan could prove effective to manage climate risk and is available to all agricultural regions of the United States as potential adaptation strategies (GCRP 2014 citing Jackson et al. 2009).

In terms of food security, reducing waste in the food system, making food distribution systems more resilient to climate risks, protecting food quality and safety at higher temperatures, and policies to ensure food access for disadvantaged populations during extreme events are all adaptation strategies to mitigate the effects of climate change (GCRP 2014 citing Walthall et al. 2012, Ericksen et al. 2009, Misselhorn et al. 2012, Godfray et al. 2010, and FAO 2011). Ultimately, adaptation will continue to become more difficult as physiological limits of plants and animal species are exceeded more frequently, and the productivity of crop and livestock systems becomes more variable (GCRP 2014).

In terms of forests, the emerging market for bioenergy—the use of plant-based material to produce energy—has the potential to aid in forest restoration (Joyce et al. 2014). Owner objectives, international markets for forest products, crops and energy, land value, and forestland policies all

influence how forestland is managed. Flexible policies that are not encumbered with legally binding regulatory requirements can facilitate adaptive management where plants, animals, ecosystems, and people are responding to climate change (Joyce et al. 2014 citing Millar et al. 2012). Ultimately, maintaining a diversity of tree species could become increasingly important to maintain the adaptive capacity of forests (Duveneck et al. 2014).

5.5.2.5 Urban Areas

This section defines urban areas and describes the existing conditions and their potential vulnerability to climate change impacts.

Urban centers are now home to over half of the global population, and this percentage continues to increase every year (IPCC 2014b citing United Nations 2012, World Bank 2008). In the United States, approximately 80 percent of the population lives in metropolitan areas[49] (GCRP 2014). In addition to large numbers of people, urban centers also contain a great concentration of the world's economic activity, infrastructure, and assets (IPCC 2014b citing United Nations 2012, World Bank 2008), many of which are aging and in need of repair or replacement (GCRP 2014). However, definitions of urban centers and their boundaries vary greatly between countries and between various pieces of academic literature. Communities between a few hundred and 20,000 inhabitants could be classified in a variety of ways, and boundaries of the urban areas vary greatly in the distance they extend from the urban core (IPCC 2014b). Definitions of urban populations frequently exclude people who live in a rural setting and commute into urban settings for work; however, they too would be impacted by the effects of climate change on their employment location (IPCC 2014b).

5.5.2.5.1 Summary

The risks of climate change to urban communities are increasing—rising sea levels, storm surges, extreme temperatures, extreme precipitation events leading to inland and coastal flooding and landslides, drought leading to increased aridity and water scarcity, and various combinations of stressors exacerbating air pollution (IPCC 2014b). These changes will have widespread impacts on the people and communities in urban areas by affecting their health, livelihoods, and belongings (such as their homes). For the global community, the IPCC suggest that these impacts will be particularly strenuous for existing vulnerable populations such as the poor, the very young and elderly, those with preexisting health conditions, and women[50] (IPCC 2014b). Climate change will have additional impacts at a larger urban scale by affecting national economics and natural ecosystems.

Climate change will profoundly affect the infrastructure that urban societies depend upon. This includes water and energy supplies, wastewater and stormwater systems, transportation, and telecommunications (IPCC 2014b). Impacts on any one of these sectors could have far reaching effects due to the interconnectedness of today's economies and the globalization of the supply chain.

The provision of social services such as healthcare, police, and education could also be affected by climate change, although less is known about these impacts. Integrating climate change considerations into these social services is necessary for their continued operation and benefit (IPCC 2014b).

[49] Metropolitan areas include urbanized areas of 50,000 or more population, plus adjacent territory that has a high degree of social and economic integration (Office of Management and Budget 2009).

[50] Women are considered at greater risk than men as they may "face discrimination in access to labor markets, resources, finance, services and influence" (IPCC 2014).

Wealthy nations are predominantly urbanized, and low- and middle-income nations are rapidly urbanizing. The rate of urbanization is outstripping the rate of investment in basic infrastructure and services, which is creating urban communities with high vulnerability to climate change (IPCC 2014b citing Mitlin and Satterwaite 2013). Across urban communities, there are very large differences in the extent to which economies are dependent on climate-sensitive resources, but in general, a high proportion of people most at risk of extreme weather events are located in urban areas (IPCC 2014b citing IFRC 2010, United Nations 2009, United Nations 2011).

5.5.2.5.2 Observed and Projected Climate Impacts

Many climate impacts are often assessed individually despite being highly interdependent; climate impacts on one sector will lead to secondary impacts on other sectors (GCRP 2014 citing Kirshen et al. 2008). For example, the 2003 electric power outage in the northeastern and midwestern United States caused the shutdown of water treatment plants and pumping stations (GCRP 2014). In today's globalized economy, the supply chains are long, and impacts on a particular sector or geographic area will have wide-ranging consequences. These knock-on effects are infrequently estimated and could be unanticipated (IPCC 2014b). In the future, infrastructure could become even more interconnected and complex, which will increase the likelihood of large-scale, cascading impacts on infrastructure (GCRP 2014 citing Ellis et al. 1997).

The clustering of essential services, such as oil refineries, contributes to urban vulnerabilities because distant damages can cause widespread losses (GCRP 2014 citing Wilbanks et al. 2012). The likelihood of these impacts is increased in the United States by the aged state of the infrastructure; significant infrastructure assets have exceeded their design lives and contribute to an increasingly fragile system (GCRP 2014).

<u>Impact on Society</u>

Certain population groups are more likely to be directly impacted by climate change than others. For example, the very young and elderly are both more sensitive to heat stress; those with preexisting health issues could be more sensitive to a range of stressors; and low-income groups and women could be more sensitive due to a lack of resources and discrimination in access to support services (IPCC 2014b, Cutter et al. 2014 citing Bates and Swan 2007, NRC 2006, Phillips et al. 2009).

The localized nature of impacts and challenges with downscaling climate data to specific locations with precision still remain (IPCC 2014b). It cannot be assumed that climate change impacts will be the same or even similar in different cities. Silver et al. (2013) demonstrate the varying impacts of climate change on two West African cities: the coastal city of Saint-Louis, Senegal, and the semi-arid Sahel city of Bobo-Dioulasso, Burkina Faso; this is a departure from the common "lumping" of West African cities into similar vulnerability categories. The paper concluded that adequately determining climate change vulnerability requires context-specific knowledge, which takes into account "geography, different climate change challenges, urban governance, and economic and cultural issues that in turn shape the economic development vulnerabilities and responses."

The process of urbanization can increase the impact of various climate stressors. For example, cities that are projected to experience rising temperatures are apt to experience temperatures even higher than projected due to the urban heat island effect (whereby the volume of paved land in urban areas absorbs and holds heat along with other causes) (IPCC 2014b). Without accounting for the urban heat island effect, using the RCP 2.6 (low emissions) scenario, it is predicted that a number of large, urban agglomerations across almost all continents will experience a temperature rise of over 1.5°C (2.7°F)

(over pre-industrial levels) by mid-century scenario and up to 2.5°C (4.5°F) by the end of the century (IPCC 2014b citing IPCC 2013b). The RCP 8.5 (high emissions) scenario suggests that, excluding urban heat island effects, urban agglomerations will experience a minimum temperature increase of 2°C (3.6°F) over pre-industrial levels by mid-century. This increased frequency of hot days will exacerbate the urban heat island effect and could lead to increased health impacts, air pollution, and increased energy demand (IPCC 2014b citing Hajat et al. 2010, Blake et al. 2011, Campbell-Lendrum and Corvalan 2007, and Lemonsu et al. 2013). However, models are beginning to show that in some locations, there could be reductions in the urban heat island effect with climate change; this is due to changes in evaporation that warm the rural surface more than the urban surface causing rural temperatures to rise, offsetting the temperature differences between the rural and urban landscape. In other areas there could be increases in the urban heat island effect (IPCC 2014b citing Früh et al. 2011, McCarthy et al. 2010, Oleson 2012). There is also increasing evidence that cities (through an urban heat island effect) can influence larger weather trends such as precipitation and lightning (IPCC 2014b citing Grimmond 2011).

Urbanization, through increased impermeable surfaces and microclimatic changes, can also increase flooding. Huong and Pathirana (2013) used a series of models to estimate flooding in Can Tho City, Vietnam, in 2100. They found that future flooding scenarios were the most severe when they considered projected changes to sea-level rise and runoff in tandem with increased precipitation due to urban growth–driven, microclimatic change (urban heat islands can increase rainfall). They projected urban growth up to 2100 based on historical growth patterns using a land use simulation model. This was coupled with a dynamic limited-area atmospheric model that considered land surface and vegetation and provided outputs on the anticipated changes in extreme rainfall due to the urban heat island effect. Lastly, this information was run through an urban-drainage/flooding model to simulate storm sewer surcharge and surface inundation to quantify the increase in flooding hazards resulting from these changes.

By the end of the century, projections of sea-level rise range from about 26 to 122 centimeters (10 to 48 inches) (IPCC 2013c [low end]; GCRP 2014 [high end]). These rising sea levels will have far reaching effects on coastal property, populations, businesses, and ecosystems, especially in combination with storms and other natural phenomena (IPCC 2014b citing Carbognin et al. 2010, Dossou and Glehouenou-Dossou 2007, El Banna and Frihy 2009, Hanson et al. 2011). These impacts were demonstrated by several recent disasters including Hurricane Sandy in New York (IPCC 2014b). Over time, coastal communities have been expanding, placing more people and resources at risk to the impacts of sea-level rise. With about a 0.5-meter (20-inch) rise in sea levels, the population at risk of coastal flooding could more than triple while asset exposure could increase up to 10 times (IPCC 2014b citing Hanson et al. 2011).

<u>Water Supply, Wastewater, and Sanitation</u>

In urban areas around the world, periods of drought and heavy rainfall are expected to increase (IPCC 2014b). Drought will have many effects in urban areas including water shortages, electricity shortages (from decreased hydropower operation), water-related diseases (which could be transmitted through contaminated water), and food insecurity. These impacts will all have negative economic consequences and could lead to increases in rural to urban migration (IPCC 2014b citing Farley et al. 2011, Herrfahrdt-Pahle 2010, Vairavamoorthy et al. 2008).

Already, an estimated 100 million people live in cities with less than 100 liters (26 gallons) of local, sustainable water per person per day, and by 2050 this number could increase to 1 billion people (this is an average across all climate scenarios) with increasing water scarcity (IPCC 2014b citing McDonald et al.

2011). Schewe et al. (2014) used 11 global hydrological models (GHMs) forced by five global climate models and a range of emissions scenarios to estimate future water scarcity. They concluded that with 2°C (3.6°F) of warming above current levels, about 15 percent more of the global population will face a severe decrease in water availability, and the number of people living under absolute water scarcity will increase by 40 percent when compared with the impacts of population growth alone. Arnell and Lloyd-Hughes (2013) determined that under the high (RCP8.5) emissions scenario the exposure to water resource stress could increase by approximately 1–3.5 billion people by 2050 and increase river flooding risks for 100–580 million people. Lower emission scenarios also suggest increasing risk but at lower levels.

Changes in precipitation due to climate change could create water demand conflicts between residential, commercial, agricultural, and infrastructure use (IPCC 2014b citing Roy et al. 2012, Tidwell et al. 2012). However, not all impacts will be negative; for example, Chicago's Metropolitan Water Reclamation District (MWRD) predicts that reduced precipitation will decrease its pumping demands because sewers will contain less rainwater in drier seasons and thus decrease operational costs (IPCC 2014b citing Hayhoe et al. 2010). Additionally, Matonse et al. (2013) used three global change models (GCMs) to develop a range of climate scenarios and found that although there will be seasonal changes in water flow, overall, New York City's water supply will continue to be highly reliable with low vulnerability to climate change.

It is projected that urban areas will be affected by changes in precipitation and water runoff and that sea-level rise will result in "saline ingress, constraints in water availability and quality, and heightened uncertainty in long-term planning and investment in water and waste water systems" (IPCC 2014b citing Fane and Turner 2010, Major et al. 2011, Muller 2007). Additionally, urban populations could be affected by "reductions in groundwater and aquifer quality, subsidence and increased salinity intrusion" (IPCC 2014b). This problem is compounded by subsidence due to high levels of groundwater extraction (which could increase with changes in precipitation), which can damage buildings and subterranean infrastructure. These impacts are already being witnessed in Bangkok, Mexico City, and Shanghai (IPCC 2014b citing Babel et al. 2006, Romero-Lankao 2010, Jha et al. 2012, de Sherbinin et al. 2007). The problem is more acute along coastlines where saltwater intrusion can further damage infrastructure and affect water quality (IPCC 2014b).

In developed and developing countries, stormwater systems will be increasingly overwhelmed by extreme short-duration precipitation events if they are not upgraded (IPCC 2014b citing Howard et al. 2010, Mitlin and Satterthwaite 2013, Wong and Brown 2009). If storm drains for transportation assets are blocked, then localized flooding can cause delays (GCRP 2014). Natural stormwater systems in urban areas are frequently built over, which blocks the natural drainage channels. These changes to the natural system combined with the frequency of development within floodplains increases the risk of future climate change driven flooding in urban areas (IPCC 2014b).

Changes in temperature and the time between precipitation events will also affect the wastewater system. Several cities in Washington State are already concerned about the design standards for their drainage systems (IPCC 2014b citing Rosenberg et al. 2010). Britain has identified climate change as a key risk to its sewer system; its models indicate that between increased flooding and increased overflow spills, Britain's volume of sewage could increase by 40 percent (IPCC 2014b citing Tait et al. 2008). New information by Langeveld et al. (2013) indicates that previous studies of impacts of climate change on wastewater systems underestimate the impacts due to model shortcomings and a single focus on precipitation events.

Energy Supply

Climate change will have direct impacts on both the production and the demand side of the energy system by changing hydropower and wind power potential, reducing the efficiency of water cooling for large electricity generating facilities, and changing demands for heating and cooling in developed countries (GCRP 2014; IPCC 2014b citing Mideksa and Kallbekken 2010). It is projected that in most cities in high-income countries, increases in summertime electricity demand due to increased air conditioning use will exceed reductions in winter time electricity use due to decreased heating demands (GCRP 2014 citing Hamlet 2010, IPCC 2014b citing Hammer et al. 2011). In the United States, the electrical grid handles almost the entire cooling load while the heating load is distributed between electricity, natural gas, heating oil, biofuel, and solar. This energy source apportionment amplifies the impact of the increased cooling load on the electrical grid (Dell et al. 2014). These overall increases in energy demand could lead to brownouts and blackouts on hot days as is already regularly experienced in Australia (IPCC 2014b citing Mideksa and Kallbekken 2010, Mirasgedis et al. 2007, Maller and Strengers 2011).

Many power supply facilities such as power plants, refineries, pipelines, transmission lines, and distribution networks are located in coastal environments and are thus subject to impacts from sea-level rise and storm surges (GCRP 2014). Brown et al. (2013) used a Geographic Information System analysis to determine vulnerable energy sites within the European coastal zone. They concluded that 158 major oil/gas/liquid natural gas/tanker terminals and 71 nuclear reactors are within the coastal zone. The vulnerability of coastal nuclear power plants was demonstrated during Hurricane Sandy when several northeast coastal nuclear reactor plants were shut down due to damages from the storm. The United Kingdom's energy network is particularly vulnerable, with three times as many coastal energy sources as any other European country. In the U.S. Gulf Coast region there are significant offshore marine and coastal facilities that will also be affected by rising sea levels and coastal storms (GCRP 2014 citing Burkett 2011).

Riverine flooding also poses a risk to the energy sector. In 2011 flooding in the Mississippi River basin surrounded a nuclear plant in Nebraska, shut down the substations, and caused wide-ranging energy shortages (Hubbard et al. 2014). Additionally, rail networks frequently follow rivers and are vulnerable to being degraded and washing out during intense precipitation events. In 2011, 42 percent of U.S. electricity was produced by coal that was transported to power plants by rail (GCRP 2014).

Power plants use water for cooling, and in the United States there are restrictions on the maximum discharge water temperature. Periods of drought and rising temperatures are apt to present challenges related to keeping discharge water below these thresholds and to permitting new power plants (GCRP 2014). Warmer discharge water can affect surrounding aquatic ecosystems (GCRP 2014).

Hydropower plants are particularly vulnerable to drought conditions (GCRP 2014). In the western United States, hydropower plants depend on steady streamflows from snowmelt and dams for continuous operation (GCRP 2014). Currently, declining water levels in the Hoover Dam raise concerns for the future of the Los Angeles power grid (IPCC 2014b citing Gober 2010). Drought will also affect the reliability of hydropower in locations such as Brazil and Saharan Africa (IPCC 2014b citing de Lucena et al. 2010, de Lucena et al. 2009, Schaffer et al. 2011, Muller 2007). Additionally, increased periods of drought can increase wildfire occurrence. Wildfires in California will affect the electricity grid by disrupting transmission and distribution lines (GCRP 2014 citing Sathaye et al. 2013).

An increase in intense storm events could collapse power lines and damage other power transmission infrastructure, leading to electricity outages (IPCC 2014b citing Rosenzweig et al. 2011).

Energy powers a substantial number of systems and critical functions in urban settings. Climate change impacts that decrease the reliability or cause disruptions to the energy supply network could have far-reaching consequences on businesses, infrastructure, healthcare, emergency services, residents, water treatment systems, traffic management, and rail shipping (IPCC 2014b citing Finland Safety Investigations Authority 2011, Halsnaes and Garg 2011, Hammer et al. 2011, Jollands et al. 2007). An example of the secondary effects of power outages is the 28-hour power outage in New York City in 2003; this outage halted mass transport, debilitated traffic management, and affected the city's water supply (IPCC 2014b citing Rosenzweig and Solecki 2010).

Oil and gas availability in the United States will be affected by increased energy demand in global markets as well as by climate change events. For example, in 2005, Hurricanes Katrina and Rita affected the natural gas, oil, and electricity markets in most of the United States with impacts being felt as far away as New York and New England (GCRP 2014 citing Wilbanks et al. 2012, AWF/AEC/Entergy 2010, Hibbard 2006, and NPCC 2009).

A recent report by DOE (2013) highlights climate vulnerabilities of the U.S. energy sector (both traditional energy sources and renewable energy) and the change in energy demand due to climate change. They support the conclusions that thermoelectric power generation is at risk of decreased efficiencies in water cooling systems due to potential heat and water shortages; warming temperatures could decrease energy demand for heating in the winter but could also increase energy demand for cooling during summer months; and significant oil and gas production as well as energy production sources are vulnerable to rising sea levels and storm surges. They also emphasize that water shortages can affect resource (oil and gas) extraction abilities; renewable energy sources (hydropower, bioenergy, and solar) will be affected by changing precipitation and temperatures; electricity transmission efficiencies will decline with increasing temperatures; transmission lines are vulnerable to damage from storms and wildfires; fuel transport via rail and barge is subject to delays due to drought and flooding; and onshore oil and gas production in Alaska will be hampered by damaged infrastructure due to permafrost melt, but offshore operations could benefit from reduced sea ice. Most of these impacts are beginning to be experienced in various regions throughout the United States. The impacts of climate change on the energy sector will vary across regions, but impacts can have cascading consequences that affect other regions.

The effect of climate change on energy in countries where large portions of urban populations do not have consistent access to electricity is relatively unknown (IPCC 2014b citing Johansson et al. 2012, Satterthwaite and Sverdilk 2012).

Transportation and Telecommunications

Transportation and telecommunications systems are susceptible to damages from extreme events. The daily and seasonal operation of most transportation systems is already sensitive to fluctuations in precipitation, temperature, winds, visibility, and for coastal cities, rising sea levels (GCRP 2014 citing Ball et al. 2010, Cambridge Systematics Inc., and Texas Transportation Institute 2005, and Schrank 2011; IPCC 2014b citing Love et al. 2010). With climate change, the reliability and capacity of the transportation network could be diminished from an increased frequency of flooding and heat events and an increased intensity of tropical storms (GCRP 2014 citing NRC 2008, DOT 2014). The cost to construct, operate, and maintain the transportation system could also increase (DOT 2014).

Telecommunication systems are also sensitive to flooding of electrical support systems, wind damages to cellular phone towers, corrosion due to flooding and sea-level rise, and unstable foundations due to permafrost melt (IPCC 2014b citing Zimmerman and Farris 2010, Larsen et al. 2008). Both

transportation and telecommunications are important for disaster response and recovery efforts including evacuation and the provision of food and water following extreme weather events (IPCC 2014b citing Jacob et al. 2011). The impacts of such events are typically experienced more deeply and for longer periods in developing nations where there are no all-weather roads and by low-income residents who are dependent on an operational public transit system (IPCC 2014b).

Transportation assets will be directly affected by a variety of climate changes. Higher temperatures will increase asphalt deterioration and reduce service life by causing pavement and rail line buckling (GCRP 2014 citing Hodges 2011, DOT 2014). Additionally, expansion joints on bridges and highways will be stressed by higher temperatures (GCRP 2014 citing Meyer 2010) and high air temperatures can affect aircraft performance and lead to delays (GCRP 2014 citing Kulesa 2003). Airports will also be affected by severe weather and precipitation events, affecting arrival and departure rates and potentially limiting aircraft range and payloads (DOT 2014). Increases in wildfires decrease visibility and can lead to the closure or roads and airports (GCRP 2014). More intense rainfall events and accelerated snowmelt can increase the likelihood of bridge damage from scour due to faster-flowing streams (GCRP 2014 citing Khelifa 2013) and flooding of underground tunnels, requiring additional drainage and pumping (DOT 2014). Transportation drainage systems and culverts could be damaged by changes in precipitation intensity and snow melt timing (DOT 2014). Rail networks are known to fail due to high temperatures, icing, and storms (IPCC 2014b). On the other hand, decreased snow can lead to reduced snow removal costs and longer construction seasons (GCRP 2014).

Transportation assets in coastal locations are particularly vulnerable to climate change impacts. In the Gulf Coast region of the United States, 27 percent of major roads, 9 percent of rail lines, and 72 percent of ports are within 4 feet of current sea levels. When potential storm surge impacts are considered, even more transportation assets are vulnerable to sea-level rise and land subsidence (IPCC 2014b citing Savonis et al. 2008). A case study in Hampton Roads, Virginia, found similarly high coastal vulnerabilities and less severe but still present inland risks (Wu et al. 2013). Additionally, 13 of the nation's largest 47 airports are within 12 feet of current sea levels (GCRP 2014 citing FAA 2012). Examples of damage to coastal infrastructure resulting from sea-level rise, storm surge, and waves include:

- Damage to coastal bridges due to waves and storm surge (Douglass et al. 2014).
- Damage to roadways and railways due to waves and storm surge (Douglass et al. 2014).
- Damage to roadways on coastal bluffs from bluff erosion and shoreline recession due to waves and wave run-up (Douglass et al. 2014).
- Damage resulting from flooding or overtopping of highways and tunnels (Douglass et al. 2014, DOT 2014).
- Shortened infrastructure life from increased frequency and magnitude of storm surge and sea-level rise (DOT 2014).

Hurricanes create high winds and storm surges that cause flooding, both of which can disrupt all transportation systems within the affected area (GCRP 2014). In 2012, Hurricane Sandy demonstrated this by shutting down New York City's bridges, tunnels, and airports. In addition, an estimated 230,000 vehicles were damaged (GCRP 2014 citing National Insurance Crime Bureau 2013), and all electrical signaling and power systems in the tunnels had to be cleaned and repaired (GCRP 2014).

Ports and harbors could have to be reconfigured to accommodate higher sea levels and large vessel clearance under bridges will need to be considered (DOT 2014, GCRP 2014). Even if the elevation of the port is sufficient, the roads and rail lines that access the port could be subject to more frequent inundation, thus affecting port activities (GCRP 2014). Additionally, shipping channels could become

blocked due to increased sediment transport with extreme floods and storms (GCRP 2014). Droughts can cause similar problems by leading to lower vessel drafts on navigable rivers (GCRP 2014). For the week following Hurricane Sandy in New York, one of the busiest container shipping ports in the United States was debilitated due to damage from the storm (IPCC 2014b citing Hallegatte et al. 2013). The impacts of this storm were felt across the country due to this port closure and other disruptions to the economy.

Transportation systems can also be affected indirectly by climate change leading to changing mode choices, trade flows, energy use, and land use patterns (GCRP 2014; DOT 2014). For example, if crop cultivation shifts farther north with rising temperatures, then distribution networks for those crops would need to be altered, which could affect the use of various network links (GCRP 2014 citing Vedenov 2011; DOT 2014). Changes in temperatures and precipitation have been shown to affect transit ridership, bicycling, and walking (GCRP 2014 citing Hodges 2011, Aultman-Hall et al. 2009, and Guo et al. 2007).

The National Cooperative Highway Research Program (NCHRP) recently released a report on the potential impacts of climate change on highways in the United States (2014). Highlights of its findings include:

- Increased temperatures can increase asset deterioration and pavement rutting.
- Extreme heat can lead to steel bridge joint expansion.
- Warmer winters could reduce the need to clear snow from roadways, but they could also increase the frequency of freeze–thaw cycles that would result in potholes and pavement heaving.
- Melting permafrost in Alaska will likely damage asset foundations and lead to decreased wintertime ice road networks.
- Increased precipitation events can lead to roadway flooding and could lead to landslides and slope failures due to increased soil moisture content.
- Bridges are vulnerable to increased wind loads as well as scour from high rates of river runoff.
- Sea-level rise (especially combined with local land subsidence and storm surge events) can lead to roadway flooding and temporary or permanent inundation.
- Underground tunnels and deep foundations could be affected by the encroachment of saltwater, which degrades many building materials.

All climate stressors will also impact the maintenance and operations of transportation assets (NCHRP 2014). For example, construction workers could have to work an altered schedule to avoid heat stroke (GCRP 2014 citing NIOSH 1986).

Hambly et al. (2013) discuss the implications of climate change on driver safety. With projected increases in high intensity precipitation events, it is expected that collision rates will increase by the mid-2050s in the Greater Vancouver Metropolitan Area. The U.S. Department of Transportation (2014) also acknowledges the increased risk of collision in severe weather and the increased risk of poor driver/operator performance and decisionmaking skills due to fatigue related to adverse weather.

Lastly, the indirect cost of climate change impacts on transportation systems, including delays and trip cancellations, could be substantial to the economy (IPCC 2014b, GCRP 2014).

Built Environment, Recreation, and Heritage Sites

Housing in urban areas is one of the pieces of infrastructure most heavily impacted by extreme weather events such as cyclones and floods (IPCC 2014b citing Jacobs and Williams 2011). Housing that is constructed out of informal building materials (usually occupied by low-income residents) and without strict building codes is particularly vulnerable to extreme events (IPCC 2014b citing United Nations 2011). Increased weather variability including warmer temperatures, changing precipitation patterns, and increased humidity accelerates the deterioration of common housing building materials (IPCC 2014b citing Bonazza et al. 2009, Grossi et al. 2007, Smith et al. 2008, Stewart et al. 2011, Thornbush and Viles 2007). Loss of housing due to extreme events and shifts in climate patterns is linked to displacement, loss of home-based businesses, and health and security issues (IPCC 2014b citing Haines et al. 2013). In 2012, the storm surge from Hurricane Sandy severely impacted coastal communities, many of them low- to moderate-income. Tens of thousands were displaced by this event, and others (especially the elderly) were left stranded on upper floors of apartment buildings without elevator service (GCRP 2014).

There is less research on the effects of climate change on urban recreation, tourism, and historical structures (IPCC 2014b). Parks and playgrounds in low-lying areas (and potentially others) such as in New York City are subject to sea-level rise and storm surge (IPCC 2014b citing Rosenzweig and Solecki 2010). Risks similar to those that apply to housing also apply to historical structures. The United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Human Settlements Programme (UN-HABITAT), European Commission, and individual city mayors have come together to assess how to protect historical structures from climate change (IPCC 2014b). Even without additional warming, the oceans will continue to expand over the next 2 millennia in response to warming that has already occurred. Marzeion and Levermann (2014) estimate that the resulting sea-level rise will lead to the inundation of 40 UNESCO Cultural World Heritage Sites. If temperatures increase by 3°C (5.4°F), 136 sites will be vulnerable to sea-level rise flooding by the time the thermal expansion of the oceans is complete (approximately 2 millennia).

Green Infrastructure and Ecosystem Services

Ecosystems will be affected by climate change induced "changes in temperature and precipitation regimes, evaporation, humidity, soil moisture levels, vegetation growth rates (and allergen levels), water tables and aquifer levels, and air quality" (IPCC 2014b). "Green infrastructure" involves using ecosystems to naturally maintain, manage, and remediate existing and new natural and urban areas. Investments in green infrastructure are projected to be affected by increasing precipitation variability, climate change, and urban heat island induced heat stress, new pest attacks, and sea-level rise inundation (IPCC 2014b citing Gaffin et al. 2012, Tubby and Webber 2010, Kithiia and Lyth 2011).

Health and Social Services

Climate change will also impact urban public services such as healthcare and social care services, education, police, and emergency services (IPCC 2014b citing Barata et al. 2011). In developed countries, existing emergency response and public health plans can be used to respond to some extreme climate events, but other events will require additional considerations (IPCC 2014b citing Bedsworth 2009 and McMichael et al. 2008). For more information on climate change and health impacts, *see* Section 5.5.1.7. In low- and middle-income countries, many of these public services are currently lacking and will only be made less available with climate change impacts (IPCC 2014b citing Brody et al. 2010).

Water shortages can lead to reliance on poorer quality water sources and can increase the likelihood of contracting waterborne illnesses. Changes in temperature extremes will also impact health through heat stress (IPCC 2014b) and changes in air quality (IPCC 2014b citing Athanassiadou et al. 2010); however, impacts of climate change on air quality in particular locations is highly uncertain (IPCC 2014b citing Jacob and Winner 2009, Weaver et al. 2009). Worsening air quality can inflame asthma and allergen problems (IPCC 2014b citing Barata et al. 2011, Gamble et al. 2009, Kinney 2008, O'Neill and Ebi 2009, Reid et al 2009). *See* Section 5.5.1.7 for additional information.

5.5.2.5.3 Adaptation

Adapting urban centers will require substantial coordination between the private sector, multiple levels of government, and civil society, but early action by urban governments is key to successful adaptation since adaptation measures need to be integrated into local investments, policies, and regulatory frameworks (IPCC 2014b). Additionally, local assessments of risks and vulnerabilities are necessary for informing appropriate adaptation strategies. While these analyses are becoming more common they are by no means comprehensive (IPCC 2014b).

Existing risk reduction plans, such as public health and natural hazard mitigation plans, provide strong foundations for the development of more comprehensive and forward thinking documents that address increasing exposure and vulnerability (IPCC 2014b). Additionally, urban areas that already have a strong government structure and universal provision of infrastructure and services are best prepared for adapting to climate change.

The provision of good quality, affordable housing would go a long way towards minimizing exposure and loss. This adaptation effort relies upon the private sector for successful implementation (IPCC 2014b). Additionally, maintaining existing infrastructure and building new infrastructure to be resilient to climate change (including water supply, sanitation, stormwater, wastewater, electricity, transport, telecommunications, healthcare, education, and emergency response infrastructure) can significantly reduce exposure and vulnerability (IPCC 2014b). Along with this built infrastructure, ecosystem services need to be considered in adaptation options (IPCC 2014b).

Financing adaptation strategies could be one of the largest hurdles to overcome; however, urban adaptation can enhance the economic competitiveness of an area by reducing risks to businesses, households, and communities (IPCC 2014b). Additionally, there are emerging synergistic options for urban adaptation measures that also deliver GHG emissions reductions co-benefits (IPCC 2014b).

5.5.2.6 Rural Areas

This section defines rural areas and describes the existing conditions and potential vulnerability to climate change impacts.

There is no clear definition of rural areas—frequently, rural areas are simply defined as areas that are not urban (IPCC 2014b citing Lerner and Eakin 2010). A consistent definition is difficult to reach because human settlements exist along a continuum from urban to rural with many varied land use forms in-between and varying development patterns between developed and developing countries. It is frequently noted that relying on the broad classifications of "urban" and "rural" is problematic for researchers (IPCC 2014b citing Simon et al. 2006:4). In general, the IPCC and this EIS accepts the definitions of urban and rural used by individual countries and individual academic authors in their work.

Rural areas are subject to unique vulnerabilities to climate change due to their dependence on natural resources, their reliance on weather-dependent activities, their relative lack of access to information,

and the limited amount of investment in local services (IPCC 2014b). These rural vulnerabilities have the potential to significantly impact urban areas due to the complex connections between the communities. For example, rural areas in the United States provide much of the rest of the country's food, energy, water, forests, and recreation (GCRP 2014 citing ERS 2012).

Rural areas account for almost half of the world's total population and an even greater percentage of people in developing countries (IPCC 2014b citing UN-DESA Population Division 2013). The U.S. Census Bureau classifies more than 95 percent of the land area in the United States as rural but only 19 percent of the population calls these areas home (GCRP citing HRSA 2012, U.S. Census Bureau 2012a, 2012b, and USDA 2012). In the United States, modern rural populations are generally more vulnerable to climate change due to various socioeconomic factors (e.g., age, income, education) (GCRP 2014).

5.5.2.6.1 Summary

Climate change will impact rural populations' water supplies (due to glacial retreat, drought, extreme precipitation events, and increasing demands on water for irrigation), food security, agricultural incomes (through shifts from growing crops to raising livestock and changing regions appropriate for the production of nonfood/high-value crops), infrastructure (including energy, transportation, and telecommunications), fisheries (due to rising ocean temperatures), and the economic benefits of rural recreation and tourism (due to declining snow packs and rising sea levels).

Rural populations in low- and medium-income countries will experience the most extreme climate change impacts due to their existing vulnerabilities to climate variability and the lack of reserves/redundancy in their critical infrastructure and services. However, increases in international trade could temporarily alleviate some of the impacts of climate change, such as food scarcity (IPCC 2014b).

Gradual changes in the climate are unlikely to affect human migration due to larger stresses such as social and political change. However, there will be substantial migration following extreme events and loss of land due to sea-level rise (IPCC 2014b).

5.5.2.6.2 Observed and Projected Climate Impacts

Climate change affects rural areas through a complex string of impacts. These impacts generally follow one of two formats: (1) extreme events that immediately impact infrastructure, and (2) long-term changes to natural systems and agriculture.

Detecting and attributing extreme events and the impacts of climate change in rural areas presents significant challenges (IPCC 2014b citing Seneviratne et al. 2012), as there are complications with relying upon traditional knowledge and farmers' perceptions to detect long-term climate trends (IPCC 2014b citing Rao et al. 2011). However, at least in Malawi, there has appeared to be a convergence between climate data and local perceptions of change over the last 30 years (IPCC 2014b citing Wellard et al. 2012).

Events that have a negative impact on rural areas include tropical storms which can lead to sudden flooding and wind damage, droughts and temperature extremes which can increase water scarcity and thus kill livestock and effect agricultural yields (IPCC 2014b citing Handmer et al. 2012 and Erickson et al. 2012), inland flooding, and wildfires (Hales et al. 2014). In the United States, rural areas have already experienced crop and livestock loss from extreme drought and flooding (GCRP 2014 citing Peterson et al. 2012), infrastructure damage to levees and roads from extreme storms (GCRP 2014 citing DOT 2010), shifts in agricultural planting and harvesting seasons (GCRP 2014 citing Kunkel et al. 2009), and large-

scale losses from wildfires and other weather-related disasters (GCRP 2014 citing Westerling et al. 2006). In Alaska, shrinking sea ice and changing seasonal ice are affecting indigenous peoples (IPCC 2014b citing Ford 2009, Beaumier and Ford 2010, IPCC 2014b). Glacial retreat in Latin America is clearly impacting rural life in highland Peru where there have been observed rapid declines in dry-season streamflow since 1962 (IPCC 2014b citing Orlove 2009).

In Asia and the Pacific, it is estimated that 42 million people have been displaced by extreme weather events between 2010 and 2011 (IPCC 2014b citing Asian Development Bank 2012). While this migration of peoples cannot be solely attributed to climate change, it could have been modified or exacerbated by climate change induced events.

The reminder of this section will focus on the impacts on rural agricultural livelihoods, non-food crops, livestock and fisheries, and water as an input to agriculture. In general, it is agreed that some African countries will experience higher losses than other regions. This holds true across a suite of climate models and emission scenarios (IPCC 2014b citing World Bank 2010a, Watkiss et al. 2010, Collier et al. 2008).

Economic Base and Livelihoods

Climate change will affect the ability of rural communities to maintain their ways of life. Rural livelihoods are less diverse than their urban counterpoints and are frequently dependent on natural resources that have unknown future availability such as agriculture, fishing, and forestry (IPCC 2014b, GCRP 2014). Due to this lack of economic diversity, climate change will place disproportionate stresses on the stability of these communities (GCRP 2014). The impacts of climate change will be amplified by the impacts on surrounding sectors within rural communities' spheres of life, such as impacts on economic policy, globalization, environmental degradation, human health, trade, and food prices (IPCC 2014b citing Morton 2007 and Anderson et al. 2010). In addition, the post-harvest aspects of agriculture such as storage and transport of crops will be affected by changes in temperature, rainfall, humidity, and extreme events (IPCC 2014b). However, in the short term, the U.S. agricultural system will likely be able to maintain its crop production by expanding irrigated land, by practicing crop rotations or shifting to different crops, and through changes in management decisions (GCRP 2014).

The increasing percentage of non-agricultural livelihoods in rural and peri-urban areas will also be affected by climate change but there is a scarcity of literature on this subject (IPCC 2014b).

Local warming "in excess of 1°C [1.8°F] is projected to have negative impacts in both temperate and tropical regions without adaptation (though individual locations may benefit). There is *medium confidence* in large negative impacts of local increases of 3 to 4°C [5.4 to 7.2°F] on productivity, production, and food security, globally and particularly in tropical countries" (IPCC 2014b).

Water

In lakes and riparian areas, it is projected that there will be an increase in algal blooms and invasive species due to rising temperatures. This will particularly be an issue in locations that already face limited sources of clean water (GCRP 2014 citing Hansson et al. 2012). Additionally, with increased intensity and frequency of precipitation events, there will be an acceleration of soil erosion rates; this erosion will diminish water quality by depositing nitrogen and phosphorous into waterbodies and by increasing algae blooms (GCRP 2014 citing Delgado et al. 2011).

Rural areas frequently depend on groundwater extraction and irrigation for local agriculture, but the availability of water from these sources is infrequently considered in projections of future crop yields

(IPCC 2014b citing Lobell and Field 2011). Reduced surface water will increase the stress on groundwater and irrigation systems (GCRP 2014).

Around the world, competition for water resources will increase with population growth and other uses such as energy production (IPCC 2014b, GCRP 2014). High temperatures increase energy demand for air conditioning which leads to increased water withdrawal for energy production. At the same time, the heat also dries out the soil which increases irrigation demands, and the warmer water threatens to shut down energy production (GCRP 2014). In the United States, water withdrawals for generating electricity in thermal power plants already roughly equals irrigation withdrawals, and this tension is expected to continue (NCA 2014 citing Hutson 2004). Multiple water crises are expected to result from increasing demand. In particular, Asian river basins could experience water scarcity and food security issues (IPCC 2014b citing Immerzeel et al. 2010). In parts of Asia and the western United States, Haddeland et al. (2013) found that anthropogenic water use (mostly for irrigation) will lead to significant future water shortages; these water shortages will be twice as severe if coupled with a 2 to 3°C (3.6 to 5.4°F) increase in global mean temperatures. Demand for irrigation water will increase with an increase in global mean temperatures which will lead to irrigation water scarcity in areas such as southern and eastern Asia (Haddeland et al. 2013). In Africa, it is predicted that there will not be widespread catastrophic failure of the rural groundwater supplies, but there could be stress on groundwater aquifer refill in rural areas where annual rainfall is only between 200 and 500 millimeters (7.9 and 19.7 inches), annually affecting up to 90 million people (IPCC 2014b citing Macdonald et al. 2009). In southern Europe, changes in rainfall and meltwater from glacial ice and snow could impact the cost of production of agriculture, and thus, raise the cost of living (IPCC 2014b citing Falloon and Betts 2010).

Non-Food Crops and High-Value Food Crops

Non-food crops and high-value food crops such as cotton, wine grapes, beverage crops (coffee, tea, and cocoa), and other cash crops contribute to an important source of income to rural locations. However, these crops tend to receive less study than staple food crops (IPCC 2014b). Cotton yields are projected to rapidly decrease with changes in temperature and precipitation (IPCC 2014b citing Easterling et al. 2007). In Israel, between 2070 and 2100, cotton cultivation could decline from the base 1960 through 1990 levels by 52 percent to 38 percent under the higher (A2) and lower (B2) emissions scenarios, respectively (IPCC 2014b citing Haim et al. 2008).

Wine grapes will be impacted but not as rapidly as other crops. It is anticipated that in California the yield variation will be limited to within 10 percent (IPCC 2014b citing Gatto et al. 2009). However, wineries could have to shift the varietals that they grow, and new regions could become better suited to growing wine grapes. Across all Mediterranean climate regions, Hannah et al. (2013) found that under the higher emissions scenario (RCP 8.5), by 2050 the historical areas suitable for viticulture could decrease by 25 to 73 percent. Under the lower emissions scenario (RCP 4.5), changes in suitable areas for viticulture are anticipated to be reduced by 19 to 62 percent. However, it is possible that viticulture could shift to non-traditional regions that, with climate change, become more suitable for growing grapes.

Coffee is historically sensitive to changes in temperature and precipitation. Coffee production in Mexico is likely to decline by 34 percent by 2020 if climatic trends from 1969 through 1990 of decreased spring precipitation and increased summer and winter temperatures continue. This would reduce profits by 90 percent (IPCC 2014b citing Gay et al. 2006). Brazil, the world's largest coffee grower, will see substantial decreases in the suitability of coffee production in some states while other states will only be partially affected. While some new areas will become suitable for coffee production, these new areas will not make up for the loss of suitable areas experienced with a 3°C (5.4°F)-increase in temperatures (IPCC

2014b citing Pinto et al. 2007, Pinto and Assad 2008). Similar changes of 30 to 60 percent loss in land suitable for coffee growing is projected in parts of Africa and South and Central America over the next few decades (IPCC 2014b). Overall, there is a worldwide projected reduction in areas suitable for coffee production by 2050 (IPCC 2014b citing Laderach et al. 2010).

Livestock/Fisheries

Livestock will be affected by droughts and heat stress, declines in forage/rangeland areas, and changes in diseases (IPCC 2014b). In general, livestock and climate change have been understudied but they remain critical to rural populations. More land could be converted to livestock (sheep and goat) production once it can no longer bear crops (IPCC 2014b citing Seo and Mendelsohn 2007a). Large-scale beef production could decline because these are generally non-diversified productions with already high stress on their systems (IPCC 2014b citing Seo and Mendelsohn 2007b).

Pastoralists lead nomadic lives in pursuit of high-quality grazing land. Their traditional way of life is well accustomed to adapting to a changing climate, but pressures to decrease their mobility is increasing in sub-Saharan Africa and inner Mongolia, making these communities subject to climate change impacts in arid and semi-arid regions (Krätli et al. 2013, IPCC 2014b citing Lioubimtseva and Henebry 2009, Fraser et al. 2011).

Fisheries could be affected by changes in fish stock distribution and abundance due to changes in their habitats and destruction of fishing infrastructure in storm events (IPCC 2014b citing Badjeck et al. 2010). Over the last 40 years, with increasing ocean temperatures, fisheries in the subtropics and temperate regions of the globe have been experiencing a shift in catch from colder-water species to warmer-water species as fish migrate to higher latitudes and deeper waters to remain within their preferred mean water temperature zone (Cheung et al. 2013). In the tropics, overall fish populations are declining as tropical fish migrate to colder waters at higher latitudes (Cheung et al. 2013). This trend is expected to continue with some mountain and cold water species declining in range and warmer species, such as bass, expanding in range (GCRP 2014 citing Janetos et al. 2008). The decline in cold water fish, such as salmon, will significantly impact traditional Inuit populations who depend on salmon as a food source (GCRP 2014). In the Mediterranean Sea, Tzanatos et al. (2014) found that there is a strong year-to-year correlation between warmer than average annual water temperatures in the late 1990s and decreases in the catch of 25 out of 59 commercial fish species. However, in those same years there has been an increase in the catch of species with short life spans (approximately 11 of the 59 fish demonstrated this correlation).

A less researched area is the effect of climate change on mining operations (GCRP 2014). These operations frequently support rural communities with few other economic options; if a mine's economic viability falters then so does that of the community. Mining and extraction will be affected by changes in the water, energy, and transportation sectors (IPCC 2014b, GCRP 2014).

Infrastructure

Impacts of climate change on rural infrastructure is similar to that in urban areas (*see* Section 5.5.1.5) but frequently there is less redundancy in the system so assets are more vulnerable to hydroclimatological events (GCRP 2014, IPCC 2014b citing NRC 2008). River flooding, sea-level rise, and coastal storms will damage transportation infrastructure and lead to the temporary loss of land activities either directly or through increased sediment transport; this can overwhelm roads or clog reservoirs (IPCC 2014b citing Kirshen et al. 2008, GCRP 2014 citing Gill et al. 2009). Alternatively, decreased

precipitation can decrease sediment transport and allow for easier operation of some infrastructure (IPCC 2014b citing Wang et al. 2007).

Warmer temperatures will lead to thawing of the permafrost in the arctic which will destabilize roads, rails, runways, pipelines, telecommunications, and bridges that are constructed on permafrost (Schwartz et al. 2014 citing Arctic Council 2009, IPCC 2014b citing Prowse et al. 2009). In Alaska, under the moderate (A1B) emissions scenario, this could lead to a 10 to 20 percent increase in public infrastructure costs from 2007 through 2030 and a 10 to 12 percent increase from 2007 through 2080. These cost increases sum to billions of dollars over both of the analysis time periods (IPCC 2014b citing Larsen et al. 2008). Additionally, warmer temperatures in the winter months could result in a loss of sea ice which could increase shipping opportunities but also reduce coastal protection leading to erosion of the shoreline and coastal roads. Canada could have to replace its winter road network which serves rural areas and lucrative mining activities if there is a 2 to 4°C (3.6 to 7.2°F) change in ground surface temperatures (IPCC 2014b citing Furgal and Prowse 2008).

Spatial and Regional Interconnections

Rural communities are becoming more connected to urban ones, but human migration from rural to urban areas is likely no higher under climate change than under regular conditions. This diverges from previous assumptions of increased migration (IPCC 2014b). There will be increased migration following extreme events that lead to the destruction of local communities, but there will be little migration due solely to slow environmental degradation. More migration will be linked to additional stressors such as political instability and socioeconomic factors (IPCC 2014b citing van der Geest 2011). However, Native American communities are already being forced to relocate due to rising sea levels and coastal erosion (GCRP 2014). In the future, rural communities on low-lying islands and atolls will have to relocate due to sea-level rise (Birk and Rasmussen 2014).

International trade (both volume and value) is expected to increase *(medium agreement and limited evidence*) by "altering the comparative advantage of countries and regions and given its potential impact of agricultural prices" (IPCC 2014b citing Nelson et al. 2009b, 2010, 2013b, Tamiotti et al. 2009). In general, exports from developed to developing countries are expected to increase, this would lower the global cost of food and thus help alleviate food insecurity, but caution should be exercised to ensure that the increased crop land is not leading to detrimental environmental consequences from loss of forests (IPCC 2014b citing Verburg et al. 2009, Schmitz et al. 2012, and Lotze-Campen et al. 2010). Increased production of biofuels will decrease emissions but could have negative benefits on society as well. Biofuel production will affect rural societies by increasing water demand, affecting water quality, and altering land uses (IPCC 2014b citing Delucchi 2010). Additionally, in 2012, drought led to poor corn harvests in the United States, intensifying concerns about mandated ethanol use and the tension between harvests being allocated to biofuels versus food (Hubbard et al. 2014).

Investment in rural communities could vary with climate change. Areas that will be negatively affected will likely not attract many investors, while regions that will become more suited for development and production will receive increased investment (IPCC 2014b).

Recreation and Tourism

There is a strong link between biodiversity, tourism, rural livelihoods, and rural landscapes in both developed and developing countries (IPCC 2014b citing Nyaupane and Poulde 2011, Scott et al. 2007, Hein et al. 2009, Wolfsegger et al. 2008, and Collins 2008). Tourism patterns could be affected by changes to the length and timing of seasons, temperature, precipitation, and severe weather events

(GCRP 2014). Changes in the economic values of traditional recreation and tourism locations will affect rural communities because tourism makes up a significant portion of rural land use (IPCC 2014b citing Lal et al. 2011). Coastal tourism, nature-based tourism, and winter sports tourism could be affected by climate change. Coastal tourism is vulnerable to cyclones and sea-level rise (IPCC 2014b citing Klint et al. 2012a, Payet 2006) as well as beach erosion and saline intrusion (IPCC 2014b). The Florida Everglades and Florida Keys are particularly threatened by sea-level rise (GCRP 2014 citing Stanton and Ackerman 2007). Some areas, such as Maine, may see increases in coastal tourism due to warmer summer months (GCRP 2014 citing Burkett and Davidson 2012). Nature-based tourism will be affected by declining biodiversity and harsher conditions for trekking and exploring (IPCC 2014b citing Thuiller et al. 2006, Nyaupane and Chhetri 2009). Winter sport tourism will be affected by declining snow packs and precipitation falling more frequently as rain rather than snow due to warmer temperatures (IPCC 2014b). In the western United States, snow accumulation has already decreased and is projected to continue to decrease due to increasing temperatures (GCRP 2014). Similar changes are expected in the northeastern United States (GCRP 2014 citing Pietrowsky et al. 2012). Tourism itself has led to increased vulnerability to climate change by encouraging coastal development in the Caribbean (IPCC 2014b citing Potter 2000).

5.5.2.6.3 Adaptation

Rural adaptation will build upon community responses to past climate variability; however, this could not be enough to allow communities to fully cope with climate impacts (IPCC 2014b). Temporary responses to food and water shortages or extreme events could even increase the long-term vulnerability of a community. For example, in Malawi, forest resources are used for coping with food shortages, but this deforestation enhances the community's vulnerability to flooding (IPCC 2014b citing Fisher et al. 2010). Therefore, it could be necessary to look beyond local examples of adapting and borrow adaptation strategies from other regions that are already experiencing more severe climate trends. This will allow for the development of long-term strategies that not only respond to climate events but minimize future vulnerabilities (IPCC 2014b citing Vincent et al. 2013). Funding for adaptation in rural areas could be linked to other development initiatives that aim to reduce poverty or generally improve rural areas (IPCC 2014b citing Nielsen et al. 2012, Hassan 2010, Eriksen and O'Brien 2007).

5.5.2.7 Human Health

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on the human health sector in the United States and globally. This section describes the climate impacts related to heat and cold events, air quality, aeroallergens, water- and food-borne diseases, vector-borne diseases, cancer, and indirect impacts on health.

5.5.2.7.1 Summary

The state of the science shows that climate change can affect human health in a variety of ways. These effects range from direct impacts from extreme temperatures and extreme weather events, to changes in prevalence of diseases, and indirect impacts from changes to agricultural productivity, nutrition, conflict, and mental health. Across all potential impacts, disadvantaged groups such as children, elderly, sick, and low-income populations are especially vulnerable.

5.5.2.7.2 Observations and Projections of Climate Impacts

Heat and Cold Events

One direct way that climate change is projected to affect human health is through changes in temperature extremes. This effect has been seen in the past and is projected to continue and worsen in the future. For example, the 2003 heat wave in Europe was responsible for about 15,000 excess deaths in France alone (IPCC 2014b citing Fouillet et al. 2008), and there is a 75 percent chance that the heat wave can be attributed to climate change (IPCC 2014b citing Christidis et al. 2012). The United Kingdom could experience a 257 percent increase in heat-related deaths by the 2050s compared to an annual baseline of 2,000 deaths under the moderate (A1B) emissions scenario and assuming no adaptation (conversely, cold-related deaths could decline by 2 percent from the current baseline of 41,000 deaths) (Hajat et al. 2014). Across 105 U.S. cities, an increase in average annual temperature of 5°F could lead to an increase in mortality by 1,907 deaths per summer, even with additional adaptation measures instigated to cope with heat (Bobb et al. 2014). However, one new study notes that projections of heat-related mortality could be overly simplified in that they often are based on only one temperature variable and do not account for variable urban heat island effects across locations and times of day (Hondula et al. 2014).

The largest health impacts from heat events are likely to occur in tropical developing countries, where large and already vulnerable populations would be exposed (IPCC 2014b citing Wilkinson et al. 2007). Further, in all parts of the world, the youngest, oldest, and poorest members of society are most vulnerable to health impacts from heat and cold events (GCRP 2014). For example, those with lower incomes could have less access to air conditioning/heating (IPCC 2014 citing Ostro et al. 2010) or could have jobs with physically strenuous working conditions (IPCC 2014b citing Kjellstrom et al. 2011, Kjellstrom et al. 2009, and Sahu et al. 2013).

Warming associated with climate change could contribute to a decline in cold-related deaths, but evidence suggests that the impacts from extreme heat events greatly outweigh any benefits from decreases in cold-related deaths (IPCC 2014b citing Ebi and Mills 2013 and Kinney at al. 2012, GCRP 2014 citing Medina-Ramón and Schwartz 2007, Yu et al. 2011, and Li et al. 2013, Hajat et al. 2014).

Air Quality

Climate change may also negatively affect human health by increasing ground-level ozone or particulate matter in some locations, degrading air quality. Ozone production could increase with rising temperatures, especially in urban areas (IPCC 2014b citing Chang et al. 2010, Ebi and McGregor 2008, Polvani et al. 2011, and Tsai et al. 2008). Even small increases in ground-level ozone concentrations can affect health (IPCC 2014b, GCRP 2014 citing Dennekamp and Carey 2010, Kampa and Castanas 2008, Kinney 2008, and Anderson et al. 2012). For example, one study projects that emergency room asthma visits associated with ozone exposure could increase by 5 to 10 percent in the New York metropolitan region under the higher (A2) emissions scenario by the mid-2020s relative to the mid-1990s (GCRP 2014 citing Sheffield et al. 2011a).

Climate change can also affect air quality through an increasing number of wildfires and changing precipitation patterns. Wildfires produce particulate matter pollutants that diminish both air quality and human health (GCRP 2014). Thus, climate change could degrade air quality through a variety of mechanisms, including increased temperatures and wildfires as mentioned, but also changes in vegetative growth, increased summertime stagnation events, and increased absolute humidity (Peel et al. 2013). Further, climate change is projected to increase flooding in some locations both in the United

States (GCRP 2014 citing IPCC 2007, IPCC 2012) and around the world (IPCC 2014b citing IPCC 2012). Combined with higher air temperatures, this could foster the growth of fungi and molds, diminishing indoor air quality, particularly in poor communities (GCRP 2014 citing Fisk et al. 2007, Institute of Medicine 2011, Mudarri and Fisk 2007, and Wolf et al. 2010).

Aeroallergens

Increased temperatures and CO_2 concentrations can shift or extend plant growing seasons, including those of plants that produce allergens and pollen (GCRP 2014 citing Sheffield et al. 2011a, Emberlin et al. 2002, Pinkerton et al. 2012, Schmier and Ebi 2009, Shea et al. 2008, Sheffield and Landrigan 2011, and Ziska et al. 2011). These effects are already occurring worldwide and are projected to continue with climate change (D'Amato et al. 2013, GCRP 2014, IPCC 2014b). For example, in central North America, length of the season for ragweed pollen has increased between 11 and 27 days in response to rising temperatures between 1995 and 2011 (GCRP 2014 citing Ziska et al. 2011).

Increases in pollen and other aeroallergens can exacerbate asthma and other health problems such as conjunctivitis and dermatitis (IPCC 2014b citing Beggs 2010). It has also been known to reduce school and work productivity (GCRP 2014 citing Ziska et al. 2011, Sheffield et al. 2011b, and Staudt et al. 2010).

Water- and Food-borne Diseases

Climate—in terms of both temperature and precipitation—can influence the growth, survival, and persistence of water- and food-borne pathogens (IPCC 2014b). For example, heavy rainfall promotes the transmission of water-borne pathogens and diseases such as cholera. Diarrheal disease rates are also linked to temperatures (IPCC 2014b). For example, one study projects that temperature increases due to climate change could cause an 8 to 11 percent increase in the risk of diarrhea in the tropics and subtropics by 2010 to 2039 relative to the baseline period 1961 to 1990, using the moderate (A1B) emissions scenario (IPCC 2014b citing Kolstad and Johansson 2011). Water-borne diseases have historically been more prevalent in developing countries and are likely to remain so. Yet climate change could also cause water- and food-borne diseases to become more prevalent in the United States. More frequent and intense rainfall could lead to combined sewer overflows that can contaminate water resources (IPCC 2014b citing Patz et al. 2008) and changes in streamflow rates can precede diarrheal disease outbreaks like Salmonellosis and Campylobacteriosis (GCRP 2014 citing Harper et al. 2011 and Rizak and Hrudey 2008).

Similar to other climate change health impacts, children and the elderly are most vulnerable to serious health consequences from water- and food-borne diseases that could be affected by climate change (GCRP 2014).

Vector-borne Diseases

Climate change, particularly changes in temperatures, could change the range and disease-carrying ability of disease "vectors" such as mosquitos or ticks (IPCC 2014b). This, in turn, could affect the prevalence and geographic distribution of diseases such as malaria, dengue fever, Lyme disease, and West Nile virus in human populations. Some of these changes are already occurring, although the interactions between climate changes and actual disease incidence are complex and multifaceted (Altizer et al. 2013). Studies estimate that even modest warming could lead to increases in malaria transmission (IPCC 2014b citing Alonso et al. 2011 and Pascual et al. 2006), with the largest effects in tropical highland regions such as highlands in Africa and parts of South America and southeast Asia (Caminade et al. 2014). Warmer temperatures could also lead to increases in dengue transmission

(Banu et al. 2014, Colón-González et al. 2013). Disease control activities have reduced malaria incidence despite warming temperatures over recent decades (IPCC 2014b citing Stern et al. 2011 and Omumbo et al. 2011). Climate-induced changes, however, could make it even more difficult for the international public health community to combat these diseases.

Ticks can cause tick-borne encephalitis, Lyme disease, Borrelia, and other diseases. In North America, ticks have expanded their habitat northward in the period 1996 to 2004 (IPCC 2014b citing Ogden et al. 2010), though there is no evidence yet of a corresponding change in distribution of tick-borne diseases. Tick-borne diseases are affected by a complex array of social and environmental factors and are thus difficult to attribute to climate change (IPCC 2014b citing Gray et al. 2009).

Vector-borne diseases such as the ones listed above are generally more common in developing countries. However, Lyme disease, dengue fever, West Nile virus, Rocky Mountain spotted fever, plague, and tularemia affect people in North America today (GCRP 2014 citing Mills et al. 2010, Diuk-Wasser et al. 2010, Ogden et al. 2008, Keesing et al. 2009, Centers for Disease Control 2013, Degallier et al. 2010, Johansson et al. 2009, Jury 2008, Kolivras 2010, Lambrechts et al. 2011, Ramos et al. 2008, Gong et al. 2011, Morin and Comrie 2010, Centers for Disease Control 2012, and Nakazawa et al. 2007). Recent research has demonstrated that the range of the Asian Tiger mosquito, a carrier for West Nile virus, could expand in the northeastern United States (Rochlin et al. 2013). Additional research is needed to better understand whether climate change will increase the risk of these diseases and others (e.g., chikungunya, Chagas disease, and Rift Valley fever viruses) in the United States (GCRP 2014).

Cancer

Climate change could alter temperature, precipitation, and cloud cover, which can alter sun exposure behavior and change the risk of ultraviolet (UV) ray-related health outcomes. However, UV exposure is influenced by several factors, and scientists are uncertain whether it will increase or decrease because of climate change. For example, one study estimates that the effective UV dose increases 2 percent for every 1.8°F (1°C) increase in average temperatures (IPCC 2014b citing van der Le un et al. 2008). This was supported by the study's findings that, in the United States, the number of cases of squamous cell carcinoma increased 5.5 percent and basal cell carcinoma increased 2.9 percent for every 1.8°F (1°C) increment in average temperatures (IPCC 2014b citing van der Leun et al. 2008). However, increasing UV exposure can also have some beneficial effects in terms of Vitamin D levels (IPCC 2014). Further, UV radiation levels are expected to decrease throughout the century because of ozone layer recovery (IPCC 2014b citing Correa et al. 2013), although changing temperatures could also change the amount of time people spend outdoors (IPCC 2014b citing Belanger et al. 2009), further influencing implications for skin cancers.

Indirect Impacts on Health

In addition to the effects outlined above, climate change can influence human health through several indirect mechanisms. For example, climate change could impact agricultural production or lead to higher food prices through extreme weather events and heat waves (IPCC 2014b citing Auffhammer 2011 and Williams and Funk 2011). African maize yields have been shown to decrease by 1 percent for each degree above 86°F (30°C), even under optimal rainfall conditions (IPCC 2014b citing Lobell et al. 2011). Reduced agricultural production and higher food prices both contribute to undernutrition (IPCC 2014b). Scientists project this impact will be largest in areas that are already food insecure (IPCC 2014b citing Knox et al. 2012). Climate change can also impact nutrition by harming marine food sources — for example, climate change can lead to marine diseases in corals, shellfish, and other seafood, and this

affects human health both through reduced food supply and, in some cases, potential disease transmission (Burge et al. 2014).

Climate change can also influence mental health. Extreme weather conditions (e.g., floods, droughts, heat waves, and severe storms) can increase stress population-wide, which can exacerbate mental health problems for those who already have them and even create them in those without (IPCC 2014b). For example, research has shown high levels of anxiety and post-traumatic stressor disorder among people affected by natural disasters such as Hurricane Katrina (GCRP 2014 citing Galea et al. 2007, Kessler et al. 2008, Ahern et al. 2005, Fewtrell and Kay 2008, Hansen et al. 2008, and McFarlane et al. 2009). Stress, induced by climate change or other factors, can also result in pregnancy-related problems such as pre-term birth, low birth weight, and maternal complications (GCRP 2014 citing Harville et al. 2009 and Xiong et al. 2008). Outside of discrete extreme weather events, heat can also affect mental health and has been known to increase suicide rates, dementia, and problems for patients with schizophrenia (GCRP 2014 citing Bouchama et al. 2007, Bulbena et al. 2006, Deisenhammer 2003, Hansen et al. 2008, Maes et al. 1994, Page et al. 2007, Basu and Samet 2002, Martin-Latry et al. 2007, and Stöllberger et al. 2009).

Climate change can also affect human exposure to toxic chemicals such as arsenic, mercury, dioxins, pesticides, pharmaceuticals, algal toxins, and mycotoxins through several pathways (Balbus et al. 2013). For example, climate change could cause mercury concentrations in fish to increase because increases in temperature could increase mercury mobility (Balbus et al. 2013 citing Riget et al. 2010). Finally, climate change could stress water and other natural resources, and lead to conflict (*see* Section 5.5.1.7). Violent conflict can have serious human health consequences.

5.5.2.7.3 Adaptation

As clear from the above, climate change could stress society's ability to manage existing human health risks as well as create additional risks to manage. The scientific community is advancing ways to manage these risks and adapt to the health impacts of climate change. The IPCC (2014b) characterizes three primary ways to adapt: incremental adaptation, transitional adaptation, and transformational adaptation. Incremental adaptation covers improvements to basic public health and healthcare services, such as vaccination programs and post-disaster initiatives (IPCC 2014b). Transitional adaptation refers to policies and measures to actively incorporate climate change considerations, such as vulnerability mapping, while transformational adaptation will involve more drastic system-wide changes and has yet to be implemented in the health sector (IPCC 2014b).

The public health community has identified several potential adaptation strategies to reduce the risks to human health from climate change. Early warning programs, for example, can be cost-effective ways to reduce human health impacts from extreme weather events (GCRP 2014 citing Chokshi and Farley 2012, Kosatsky 2005, Rhodes et al. 2010, and The Community Preventive Services Task Force 2013). Strategies to reduce the urban heat island effect such as cool roofs and increased green space can reduce health risks from extreme heat (GCRP 2014 citing Stone et al. 2010 and EPA 2012, Boumans et al. 2014).

Greenhouse gas reduction policies can also have health benefits by improving air quality and promoting active transportation, which can reduce rates of obesity, diabetes, and heart disease (GCRP 2014 citing Markandya 2009 and Haines et al. 2009). In addition, health adaptation strategies can have benefits beyond health, although some could also pose risks that will have to be carefully managed (Cheng and Berry 2013). Identifying new and creative ways to continue to improve human health despite climate change is an area of active research.

5.5.2.8 Human Security

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on human security in the United States and globally. IPCC defines human security in the context of climate change as "a condition that exists when the vital core of human lives is protected, and when people have the freedom and capacity to live with dignity" (IPCC 2014b). This section addresses five key dimensions of human security: (1) livelihoods, (2) cultures, (3) migration and mobility, (4) armed conflict, and (5) state integrity and geopolitical rivalry.[51]

5.5.2.8.1 Summary

As there are multiple drivers of human security, it can be difficult to establish direct causation between climate change and impacts on human security. Overall, the research literature finds that climate change has negative impacts on various dimensions of human security, including livelihoods, cultures, migration, and conflict. However, some dimensions of human security are driven more by economic and social forces rather than by climate change (IPCC 2014b).

Climate change can threaten human security in the following ways:

- **Affecting livelihoods.** Climate change can deprive people of immediate basic needs such as food, water, and shelter, or cause longer-term erosion of livelihood assets and human capital, which undermines human security.
- **Compromising cultures.** Climate change can threaten the natural resource base upon which cultures depend, thereby compromising cultural practices and values. Loss of land and displacement has had well-documented negative impacts on cultures and community well-being. Indigenous, local, and traditional forms of knowledge are a major resource to adapt to climate change, but they may not be sufficient to address projected changes in climate.
- **Increasing migration/restricting mobility.** Climate change can increase forced migration. Migrants can be more exposed to climate change impacts in new areas, such as in cities. Lack of mobility increases vulnerability to climate change.
- **Increasing risks of armed conflict.** Several factors that increase the risk of violence within countries, such as low per capita incomes, economic contraction, and inconsistent political institutions, can be sensitive to climate change. As a result, climate change can contribute to increasing conflict risk under certain circumstances. Increases in the risk of conflict abroad can have national security implications for the United States.
- **Compromising state integrity and increasing geopolitical rivalry.** Climate change can impact critical infrastructure such as transport, water, and energy, thereby reducing the ability of countries to provide the conditions necessary for human security. Sea-level rise can threaten the territorial

[51] Information on the national security implications of climate change for the United States is drawn from several recent national security reports, as peer-reviewed studies are unavailable and the issue was not analyzed in detail in the National Climate Assessment because "there are a number of recent unclassified U.S. Department of Defense (DOD) reports and reports of other groups that have rigorously addressed this topic" (GCRP 2014). The reports that were consulted are the Department of Defense's "Quadrennial Defense Review Report" (DOD 2014), the National Research Council's "Climate and Social Stress: Implications for Security Analysis" (NRC 2013), and the Center for Naval Analyses (CNA) Corporation report, "National Security and the Accelerating Risks of Climate Change" (The CNA Corporation 2014), which was researched and written under the direction of 11 retired senior military officers. The 2014 CNA Corporation report is an update of the first report in 2007, "National Security and the Threat of Climate Change" (The CNA Corporation 2007). The 2014 CNA Corporation report validates the findings of the previous report and finds that in many cases the risks of climate change are advancing faster than anticipated.

integrity of some countries such as small-island nations. Transboundary impacts of climate change such as loss of sea ice in the Arctic, migration of fish stocks, and changing shared water resources can increase geopolitical tensions. Impacts on U.S. critical infrastructure, potential disputes in the Arctic, and increased risk of conflict over other resources, including those that do not directly involve the United States, can create national security concerns for the United States (IPCC 2014b).

5.5.2.8.2 Observed and Projected Climate Impacts

Economic and Livelihood Dimensions

Economic and livelihood security includes access to food, clean water, shelter, employment, and avoidance of direct risks to health. Climate change poses significant risks to all of these aspects and can thereby threaten the economic and livelihood security of individuals or communities (IPCC 2014b).

Climate change can undermine livelihoods through depriving people of immediate basic needs such as food, water, and shelter, or through causing longer-term erosion of livelihood assets and human capabilities (IPCC 2014b). There are well-documented impacts of climate variability and change on agricultural productivity and food insecurity, water stress and scarcity, and destruction of property and residence (IPCC 2014b citing Carter et al. 2007, Leary et al. 2008, Peras et al. 2008, Paavola 2008, and Tang et al. 2009). Climate variability and change can also affect health and education, which will undermine human capital. For example, it is found that "Indian women born during a drought or flood in the 1970s were 19 percent less likely to ever attend primary school, when compared with women of the same age who were not affected by natural disasters" (IPCC 2014b citing UNDP 2007). Projections using a variety of socioeconomic and climate change scenarios suggest an increase in economic and health risks, including loss of lives, increased psychological stress associated with extreme climatic events, and decreased access to natural resources (IPCC 2014b citing Hall et al. 2003, Kainuma et al. 2004, and Doherty and Clayton 2011). These projected increases in climate change impacts will further threaten the economic and livelihood security of vulnerable populations.

In the United States, climate change is increasingly affecting food and water security (*see* Section 5.5.1.4 and 5.5.1.1), human health (*see* Section 5.5.1.7), and infrastructure and settlements (*see* Section 5.5.1.5 and 5.5.1.6). These impacts will have negative implications for the economic and livelihood security of vulnerable groups. Populations that are most at risk include the urban poor and rural and indigenous communities whose livelihoods are highly dependent upon natural resources (GCRP 2014). For example, declining sea ice, permafrost thaw, and more extreme weather and severe storms are causing increasingly risky travel and hunting conditions in Alaska, threatening traditional livelihoods of Alaska Native populations (GCRP 2014 citing Cochran et al. 2013). In Pacific island communities, warmer sea surface temperature is causing coral bleaching and affecting subsistence fisheries, which undermines traditional livelihoods and raises food security concerns (GCRP 2014 citing Maclellan 2009).

Cultural Dimensions

Climate change can compromise cultural values and practices through its impacts on livelihoods and settlements. Research has documented the impact of changes in natural resources due to changing climatic conditions on rural livelihoods and, therefore, on cultures (IPCC 2014b). Many anthropological studies indicate that further significant changes in the natural resource base would negatively affect indigenous cultures (IPCC 2014b citing Crate 2008, Gregory and Trousdale 2009, and Jacka 2009). Climate change can also cause loss of land and displacement, such as in small island nations or coastal communities, which has well-documented negative cultural and well-being impacts (IPCC 2014b citing

Bronen 2011, Johnson 2012, Arnall 2013, Bronen 2010, Bronen and Chapin 2013, and Cunsolo-Willox et al. 2012, 2013).

Cultural values and expressions are dynamic and hence inherently adaptable, and a number of studies have presented examples of cultures that persisted through significant historical upheavals (IPCC 2014b citing Nuttall 2009, Cameron 2012, and Strauss 2012). While adaptation is possible to avoid some losses of cultural assets and expressions, cultural integrity will still be compromised if climate change erodes livelihoods, sense of place, and traditional practices (IPCC 2014b).

The 400 million indigenous people worldwide are the world's greatest reserve of cultural diversity (IPCC 2014b). However, around the world it is increasingly challenging for indigenous communities to maintain cultures, livelihoods, and traditional food sources in the face of climate change (IPCC 2014b citing Crate and Nuttall 2009, Rybråten and Hovelsrud 2010, and Lynn et al. 2013). For example, declining sea ice is causing dangerous travel conditions and reducing access to traditional food in the Arctic (IPCC 2014b citing Ford et al. 2008, Ford et al. 2009, and Hovelsrud et al. 2011). In addition, traditional practices are already facing multiple stressors, such as changing socioeconomic conditions and globalization, which undermines their ability to adapt to climate change (IPCC 2004b citing Green el al. 2010).

The impacts of climate change on traditional practices and cultures are projected to vary across societies, depending on cultural and social resilience. Research has documented that "the efficacy of traditional practices can be eroded when governments relocate communities (Hitchcock 2009, McNeeley 2012, Maldonado et al. 2013); if policy and disaster relief creates dependencies (IPCC 2014 citing Wenzel 2009, Fernández-Giménez et al. 2012); in circumstances of inadequate entitlements, rights and inequality (Shah and Sajitha, 2009, Green et al. 2010, Lynn et al. 2013); and when there are constraints to the transmission of language and knowledge between generations (Forbes 2007)" (IPCC 2014b). Lack of involvement in formal government decision-making over resources also decreases the resilience of indigenous peoples and their cultures to climate change impacts (IPCC 2014b citing Ellemor 2005, Brown 2009, Finucane 2009, Turner and Clifton 2009, Sánchez-Cortés and Chavero 2011, and Maldonado et al. 2013).

Local and traditional knowledge is a valuable source of information for adapting to climate change (IPCC 2014b, GCRP 2014). There is high agreement in the literature that the integration of local and traditional and scientific knowledge increases adaptive capacity (IPCC 2014b citing Kofinas 2002, Oberthür et al. 2004, Tyler et al. 2007, Anderson et al. 2007, Vogel et al. 2007, West et al. 2008, Armitage et al. 2011, Frazier et al. 2010, Marfai et al. 2008, Flint et al, 2011, Ravera et al. 2011, Nakashima et al. 2012, and Eira et al. 2013). While being an important resource for adaptation, traditional knowledge may not be sufficient to respond to rapidly changing ecological conditions or unexpected or infrequent risks (IPCC 2014b; GCRP 2014). As a result, current traditional knowledge strategies may be inadequate to manage projected climate changes (IPCC 2014b citing Wittrock et al. 2011).

In the United States, climate change is posing particular threats to indigenous populations' traditional livelihoods and cultures, which are closely tied to the natural world. For example, climate change is causing changes in the range and abundance of culturally important plant and animal species, reducing the availability and access to traditional foods, and increasing damage to tribal homes and cultural sites (GCRP 2014 citing Lynn et al. 2013, Voggesser et al. 2013, and Karuk Tribe 2010). In parts of Alaska, Louisiana, the Pacific Islands, and other coastal locations, climate change is already forcing indigenous peoples to relocate from their historical homelands, with negative impacts on their cultures and

identities (GCRP 2014). These impacts are projected to become more severe with further changes in natural resources due to climate change.

Migration and Mobility Dimensions

Climate change can increase migration through extreme events or long-term environmental changes. Much of the literature reviewed in the IPCC Special Report on Extreme Events (IPCC SREX) suggests that an increase in the incidence and/or severity of extreme events due to climate change will directly increase the risks of displacement and amplify its impacts on human security (IPCC 2014b). Climate change-induced mass migration threatens to adversely affect the humanitarian assistance requirements of the U.S. military, as well as strain its ability to respond to conflict (NRC 2011). Displacement affects human security by impacting housing, health, and economic outcomes (IPCC 2014b citing Adams et al. 2009 and Hori and Shafer 2010).

Major extreme weather events have in the past led to significant population displacement (IPCC 2014b). However, such displacement is usually short-term, and most displaced people try to return to their original residence and rebuild as soon as circumstances allow (IPCC 2014b). As a result, only a proportion of displacement leads to more permanent migration (IPCC 2014b citing Foresight 2011 and Hallegatte 2012). For example, the Pakistan floods of 2010 resulted in primarily localized displacement rather than longer-term migration (IPCC 2014b citing Gaurav et al. 2011). Fussell et al. (2014) found that the population in New Orleans recovered gradually after Hurricane Katrina, reaching about half of its pre-Katrina size by mid-2006 and about three-quarters by mid-2012. These populations included both returning households and new immigrant households, and anecdotal evidence indicated that most were returning residents. The study also found that much of the in-migration after Hurricane Katrina was from nearby, less affected counties.

However, extreme events can sometimes be associated with immobility or in-migration instead of displacement. For example, Paul (2005) found that little displacement occurred following floods in Bangladesh and there was in-migration due to reconstruction activities (IPCC 2014b citing Paul 2005). Additionally, there is some evidence that climate change can reduce migration flows due to its impacts on productivity. As migration is resource-intensive, in some cases migration flows decreased when the households had limited resources, such as in drought years (IPCC 2014b citing Findley 1994, van der Geest 2011, and Henry et al. 2004).

Lack of mobility is associated with increased vulnerability to climate change, as vulnerable populations frequently do not have the resources to migrate from areas exposed to the risks from extreme events. When migration occurs among vulnerable populations, it is usually an "emergency response that creates conditions of debt and increased vulnerability, rather than reducing them" (IPCC 2014b citing Warner and Afifi 2013). Migration and mobility outcomes can also vary based on socioeconomic and demographic factors, as seen in the high differentiation by income, race, class, and ethnicity in emergency evacuation responses and return migration after Hurricane Katrina (IPCC 2014b citing Elliott and Pais 2006, Falk et al. 2006, and Landry et al. 2007).

A number of studies have found that migrants can face increased risks to climate change impacts in their new destinations, such as in cities (IPCC 2014b citing Black et al. 2011). For example, migrants in Buenos Aires, Lagos, Mumbai, and Dakar are often located in areas at higher risks to extreme events than long-term residents (IPCC 2014b citing World Bank 2010 and Mehrotra et al. 2011). Other studies in Shanghai and the Cayman Islands found that migrants have less knowledge about and are least likely to prepare for tropical storms (IPCC 2014b citing Wang et al. 2012 and Tompkins et al. 2009).

Simulation studies show that long-term environmental changes, sea-level rise, coastal erosion, and loss of agricultural productivity due to climate change will significantly affect migration flows (IPCC 2014b citing Lilleor and Van den Broeck 2011). These changes can amplify existing migration trends such as rural-to-urban migration. For example, some studies found that increased temperatures and drier conditions would reduce crop yield and increase the rate of emigration from Mexico to the United States (Oswald-Spring et al. 2014, IPCC 2014b citing Feng et al. 2009). Another study modelled internal migration rates within Brazil and found that the projected warming and drying trends would increase out-migration from rural areas (IPCC 2014b citing Barbieri et al. 2010).

Sea-level rise, coastal inundation, coastal erosion, and permafrost melting can lead to permanent displacements. Nicholls et al. (2011) estimated that with no adaptation investment, a 0.5-meter (1.6-foot) sea-level rise would *likely* imply the displacement of 72 million people; a 2.0-meter (6.5-foot) sea-level rise would *likely* displace 187 million people, mostly in Asia (IPCC 2014b citing Nicholls et al. 2011). Curtis and Schneider (2011) projected that 20 million people in the United States would be dislocated by sea-level rise by 2030 in four major coastal areas (northern California, New Jersey, South Carolina, and southern Florida). The study defined "at-risk" locations as those that can be inundated under two worst-case scenarios: 1-meter (3.2-foot) inundation for sea-level rise and 4-meter (13.1-foot) for storm surges/flooding. The impact of future sea-level rise is projected to extend beyond the inundated counties as displaced populations will migrate to other areas in the country (IPCC 2014b citing Curtis and Schneider 2011). In Alaska, several coastal villages are experiencing such severe coastal erosion and permafrost thaw that resettlement is the only viable option (IPCC 2014b citing Bronen 2010, Oliver-Smith 2011, and Marino 2012). The NCA reports states that more than 30 indigenous villages in Alaska are "either in need of, or in the process of, relocating their entire village" (GCRP 2014 citing Cochran et al. 2013 and Bender et al. 2011).

However, populations in at-risk areas do not always choose to migrate due to strong ties with their homelands. For example, survey residents on the island of Funafuti, Tuvalu have emphasized place attachment as reasons for not migrating, despite forecasts that the island could become uninhabitable (IPCC 2014b citing Mortreux and Barnett 2009). In another example, pastoralists displaced by a drought in Sudan in the 1990s tried to return to their original settlements after the drought despite conflict and other factors (IPCC 2014b citing Haug 2002). However, if the impacts of climate change become more pronounced, they can be a more significant driver of migration in the future (IPCC 2014b citing Adams and Adger 2013).

Armed Conflict

Most of the research on the relationship between climate change and violent and armed conflict focuses on the link between climate variability and regional or country conflicts in the modern era. Temperature or rainfall variability is used as a proxy for longer term changes that might occur due to climate change (IPCC 2014b). The association between short-term warming and deviations in rainfall (including floods and droughts) with armed conflict is contested, with some studies finding a relationship while others finding no relationship (IPCC 2014b). Most studies find that climate change impacts on armed conflict is negligible in situations where other risk factors are extremely low, such as where per capita incomes are high or governance is effective and stable (IPCC 2014b citing Bernauer et al. 2012, Koubi et al. 2012, Scheffran et al. 2012, and Theisen et al. 2013).

In response to the difficulty of finding direct relationship between climate variability and violence, some research has investigated the impacts of climate change on factors that are known to increase the risk of civil war and other armed conflicts (IPCC 2014b citing Bergholt and Lujala 2012, Koubi et al. 2012). Examples of such factors include a recent history of civil violence, low levels of per capita income, low

rates of economic growth, economic shocks, inconsistent political institutions, and the existence of conflict in neighboring countries (IPCC 2014b citing Miguel et al. 2004, Weede 2004, Hegre and Sambanis 2006, Dixon 2009, Blattman and Miguel 2010, and Brückner and Ciccone 2010). As many of these factors are sensitive to climate change, changes in average and extreme climatic conditions can increase conflict risks. For example, climate change could slow economic growth and hinder efforts to raise per capita incomes in certain low income countries, particularly in Africa where the risk of conflict is highest (IPCC citing Mendelsohn et al. 2000, Mendelsohn et al. 2006, Stern 2007, and Eboli et al. 2010). The incidence or severity of extreme events could increase due to climate change, which might cause economic shocks that would potentially increase the risk of violent conflicts (IPCC 2014b citing Bergholt and Lujala 2012, Hallegatte 2012, and Adam 2013). Increased migration due to extreme events or long-term environmental changes could increase the risk of violent conflict, particularly if the destination areas are already under environmental or social stress (IPCC 2014b, NRC 2013).

A recent study by Gleick et al. (2014) found that water and climatic conditions played a direct role in worsening Syria's economic conditions and contributed to triggering the civil war that began in March 2011. Syria experienced a multi-season, multi-year extreme drought starting in 2006 and lasting into 2011. This drought combined with inefficient water policies and systems in Syria as well as in other countries in the eastern Mediterranean region caused agricultural failures, which contributed to the displacement of populations from rural to urban centers, food insecurity for more than a million people, and increased unemployment in urban areas. Together with other social, religious, and political factors, these conditions led to widespread political unrest and violence. As climate change is expected to exacerbate water scarcity in the region, it would likely increase the risks of local and regional conflict if there are no collective efforts to improve water management and address the impacts of climate change (Gleick et al. 2014).

In summary, "there is justifiable common concern that climate change or changes in climate variability increases the risk of armed conflict in certain circumstances […] even if the strength of the effect is uncertain" (IPCC 2014b citing Bernauer et al. 2012, Gleditsch 2012, Scheffran et al. 2012, and Hsiang et al. 2013). It is, however, not possible to make confident statements regarding the impacts of future climate change on armed conflict due to the lack of "generally supported theories and evidence about causality" (IPCC 2014b).

The significant reductions in Arctic sea ice coverage resulting from climate change have increased the maritime availability of the region—both through the reduction of sea ice coverage and the disappearance of multi-year ice accumulation. Some estimates suggest a continued decline of Arctic summer sea ice at the current rate of 10 percent per decade, facilitating cross-Arctic transit by 2030 (NRC 2011). This increased accessibility threatens to increase competition between nations over new sources of petroleum, natural gas, and non-fuel minerals (NRC 2011). The Arctic region plays host to a variety of maritime boundary disputes that may be exacerbated by the increased accessibility of the region due to warmer temperatures—such as the status of Canada's Northwest Passage. Furthermore, bordering nations maintain unresolved sea and economic zone disputes in the Arctic (NRC 2011).

The potential impacts of climate change on accelerating instability in volatile regions of the world have profound implications for national security of the United States. The DOD 2014 Quadrennial Defense Review indicates that the projected effects of climate change "… are threat multipliers that will aggravate stressors abroad such as poverty, environmental degradation, political instability, and social tensions—conditions that can enable terrorist activity and other forms of violence" (DOD 2014).

State Integrity and Geopolitical Rivalry

Climate change can compromise state integrity by affecting critical infrastructure, threatening territorial integrity, and increasing geopolitical rivalry (IPCC 2014b). Climate change and extreme weather events are already affecting critical infrastructure such as water and sanitation, energy, and transportation in the United States and globally, and these impacts are projected to increase with further changes in climate (*see* Sections 5.5.1.5 and 5.5.1.6). Climate change impacts on critical infrastructure will reduce the ability of countries to provide the economic and social services that are important to human security (IPCC 2014b). Climate change can also affect military logistics, energy, water, and transportation systems, compromising the ability of the U.S. military to conduct its missions (NRC 2011, The CNA Corporation 2014, NRC 2013). Furthermore, the U.S. military could become overextended as it responds to extreme weather events and natural disasters at home and abroad, as along with current or future national security threats (NRC 2011, The CNA Corporation 2014).

Sea-level rise, storm surge, and coastal erosion can threaten the territorial integrity of small island nations or countries with significant areas of soft low-lying coasts (IPCC 2014b citing Hanson et al. 2011, Nicholls et al. 2011, Barnett and Adger 2003, and Houghton et al. 2010). Accelerating sea ice loss in the Arctic can open access to resources and allow new shipping routes, potentially increasing security concerns as a result of territorial and maritime disputes if equitable arrangements between countries cannot be agreed to (IPCC 2014b, GCRP 2014). Other transboundary impacts of climate change such as changing shared water resources and migration of fish stocks can also increase geopolitical rivalry among states (IPCC 2014b). Additionally, climate change could increase tension and instability over energy supplies (The CNA Corporation 2014). The presence of robust interstate institutions to manage disputes is critical to reducing the risk of conflict (IPCC 2014b).

5.5.2.8.3 Adaptation

Adaptation strategies can reduce vulnerability and thereby increase human security. Examples of adaptation measures to improve livelihoods and well-being include diversification of income-generating activities in agricultural and fishing systems, development of insurance systems, and provision of education for women. Integration of local and traditional knowledge is found to increase the effectiveness of adaptation strategies. Improvements in entitlements and rights, as well as engagement of indigenous peoples in decision-making, increase their social and cultural resilience to climate change (IPCC 2014b).

There is not enough evidence on the effectiveness of migration and resettlement as adaptation. Migration is costly and disruptive and is thus often perceived as an adaptation of last resort (IPCC 2014b citing McLeman 2009). Bronen and Chapin (2013) argue that the "legitimacy and success [of relocation] depend on incorporating cultural and psychological factors in the planning processes" (IPCC 2014b). In the United States, new governance institutions, frameworks, and funding mechanisms are needed to support the relocation processes of communities displaced by climate change (GCRP 2014).

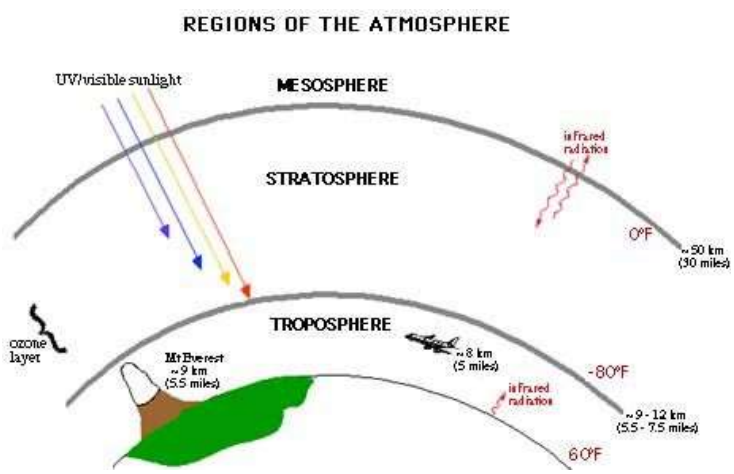
Poorly designed adaptation strategies can increase the risk of conflict and amplify vulnerabilities in certain populations, if they exacerbate existing inequalities or grievances over resources (IPCC 2014b). As a result, it is important to consider differentiated vulnerabilities and the potential impact of adaptation on conflict. In addition, investments in institutions to resolve conflicts over resources by peaceful means are critical to enhancing human security at all levels (IPCC 2014b). Recognizing the risks climate change poses to national security, the DOD is now incorporating the consequences of climate change in its long-range strategic plans, including potential impacts on its facilities and missions (GCRP 2014 citing DOD 2014).

5.5.2.9 Carbon Dioxide and Climate Change Impacts on Stratospheric Ozone

This subsection presents a review of stratospheric ozone and describes how CO_2 and climate change are projected to affect stratospheric ozone concentrations. As this topic is not addressed in the recently-released IPCC or NCA reports, this section primarily draws from journal articles and panel-reviewed reports.

Ozone in Earth's stratosphere (the upper layer of the atmosphere) absorbs some harmful UV radiation from the Sun, and therefore protects humans and other organisms (*see* Figure 5.5.2-1). Since the 1980s, satellite and ground observations have shown reductions in the concentrations of stratospheric ozone. There is an international consensus that human-made ozone-depleting substances (such as gases emitted by air conditioners and aerosol sprays) are responsible, prompting the establishment of international agreements to reduce the consumption and emission of these substances (Fahey and Hegglin 2011). In response to these efforts, the rate of stratospheric ozone reduction has slowed. Although there are elements of uncertainty, stratospheric ozone concentrations are projected to recover to pre-1980 levels over the next several decades (Fahey and Hegglin 2011, WMO 2011), with further "thickening" of the ozone layer possible by 2100 in response to climate change (IPCC 2014 citing Correa et al. 2013).

Figure 5.5.2-1. The Three Lowest Layers in Earth's Atmosphere and the Location of the Ozone Layer



Source: NOAA 2011a.

Climate change could influence the recovery of stratospheric ozone. Although GHGs, including CO_2, warm the troposphere (the lower layer of the atmosphere), this process actually cools the stratosphere, slowing the chemical reactions between stratospheric ozone and ozone-depleting substances, hence assisting in ozone recovery. However, for polar regions, cooling temperatures can increase winter polar stratospheric clouds that are responsible for accelerated ozone depletion. Climate change could enhance atmospheric circulation patterns that affect stratospheric ozone concentrations, assisting in ozone recovery in the extra-tropics. Changes in stratospheric ozone, in turn, influence climate by affecting the atmosphere's temperature structure and atmospheric circulation patterns (Ravishankara et al. 2008). In summary, climate change has been projected to have a direct impact on stratospheric ozone recovery, although there are large elements of uncertainty within these projections.

This section discusses the interaction of stratospheric ozone, climate, and trace gases using information provided by the World Meteorological Organization (WMO) Scientific Assessment of Ozone Depletion: 2010 (WMO 2011) and the U.S. Climate Change Science Program (2008) report, *Trends in Emissions of*

Ozone-depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure (CCSP 2008b). These resources remain the best available summaries of climate impacts on stratospheric ozone.

Ozone is a molecule consisting of three oxygen atoms. Ozone near Earth's surface is considered an air pollutant that causes respiratory problems in humans and adversely affects crop production and forest growth (Fahey and Hegglin 2011). Conversely, ozone in Earth's stratosphere (approximately 9 to 28 miles above Earth's surface) acts as a shield to block UV rays from reaching Earth's surface (Ravishankara et al. 2008).[52] This part of the atmosphere is sometimes referred to as the "ozone layer," and it provides some protection to humans and other organisms from exposure to biologically damaging UV rays that can cause skin cancer and other adverse impacts (Fahey and Hegglin 2011, Fahey et al. 2008).

Ozone in the stratosphere is created when a diatomic oxygen molecule absorbs UV rays at wavelengths less than 240 nanometers, causing the molecule to dissociate into two very reactive free radicals that then each combine with an available diatomic oxygen molecule to create ozone (Fahey and Hegglin 2011). Through this process, heat is released, warming the surrounding environment. Once ozone is formed, it absorbs incoming UV rays with wavelengths between 220 and 330 nanometers (Fahey and Hegglin 2011). Ozone, which is a very reactive molecule, could also react with such species as hydroxyl radical, nitric oxide, or chlorine (Fahey et al. 2008).

The concentration of ozone in the stratosphere is affected by many factors, including concentrations of ozone-depleting substances and other trace gases, atmospheric temperatures, transport of gases between the troposphere and the stratosphere, and transport within the stratosphere. Changes in climate affect many of these factors, as described in Sections 5.5.1.8.1 through 5.5.1.8.3.

5.5.2.9.1 Human-made Ozone-depleting Substances and Other Trace Gases

For the past few decades, stratospheric ozone concentrations have been declining in response to increasing concentrations of human-made ozone-depleting substances. Examples of ozone-depleting substances include chlorofluorocarbons (CFCs) and compounds containing bromine (Ravishankara et al. 2008, Fahey and Hegglin 2011). These ozone-depleting substances are chemically inert near Earth's surface, but decompose into very reactive species when exposed to UV radiation in the stratosphere.[53]

In 1987, an international agreement, the Montreal Protocol on Substances that Deplete the Ozone Layer, was established to reduce the consumption and production of human-made ozone-depleting substances in order to protect and heal the ozone layer and rebuild the ozone hole.[54] Subsequent

[52] These height measurements defining the bottom and top of the stratosphere vary depending on location and time of year. Different studies might provide similar but not identical heights. The heights indicated for the stratosphere and the layers within the stratosphere are provided in this section as defined by each study.

[53] For example, when a CFC molecule is exposed to UV radiation, it splits into a number of species, including a very reactive chlorine atom. The chlorine atom then combines with ozone, creating chlorine monoxide radical and a diatomic oxygen molecule. The chlorine monoxide radical can react with an oxygen atom (i.e., keeping the oxygen atom from reacting with diatomic oxygen to form ozone), creating the chlorine atom and another diatomic oxygen molecule. In essence, one chlorine atom has interrupted the natural ozone-producing cycle by consuming both a reactive oxygen atom and destroying an ozone molecule (Fahey and Hegglin 2011).

[54] The polar regions experience the greatest reduction in total ozone, with about a 5 percent reduction in the Arctic and 18 percent reduction in the Antarctic (Fahey and Hegglin 2011). Significant thinning in the ozone layer has been observed above the Antarctic since the spring of 1985, to such a degree it is termed the "ozone hole" (Ravishankara et al. 2008). This location is

agreements have followed that incorporate more stringent reductions of ozone-depleting substances and expand the scope to include additional chemical species that attack ozone. Some ozone-depleting substances, such as CFCs, are potent GHGs; therefore, reducing the emissions of these gases also reduces radiative forcing, and hence, reduces the heating of the atmosphere.

Increases in the emissions of other trace gases (e.g., CH_4 and N_2O) and CO_2 affect stratospheric ozone concentrations (Fahey et al. 2008). When CH_4 is oxidized in the stratosphere, it produces water.

Increases in stratospheric water lead to an increase in reactive molecules that assist in the reduction of ozone and an increase in polar stratospheric clouds that accelerate ozone depletion. Increases in N_2O emissions cause a reduction of ozone in the upper stratosphere as N_2O breaks down into reactive ozone-depleting species. CO_2 emissions affect atmospheric temperature; the impact on stratospheric ozone is discussed below.

5.5.2.9.2 Changes in Atmospheric Temperature

Since the observational record began in the 1960s, global stratospheric temperatures have been decreasing in response to ozone depletion, increased tropospheric CO_2, and changes in water vapor (Fahey et al. 2008). Natural concentrations of GHGs increase the warming in the troposphere by absorbing outgoing infrared radiation; increasing GHG concentrations in the troposphere traps more heat in the troposphere, which translates to less incoming heat into the stratosphere. In essence, as GHGs increase, the stratosphere is projected to cool. However, model simulations suggest reductions in ozone in the lower to middle stratosphere (13 to 24 miles) create a larger decrease in temperatures compared to the influence of GHGs (Fahey et al. 2008 citing Ramaswamy and Schwarzkopf 2002).

Above about 24 miles, both the reductions of ozone and the impact of GHGs can contribute significantly to stratospheric temperature decreases.

The cooling temperatures in the stratosphere could slow the loss of ozone (Fahey et al. 2008). In the upper stratosphere, the dominant reactions responsible for ozone loss slow as temperatures cool. For example, ozone in the upper stratosphere is projected to increase by 15 to 20 percent under a doubled CO_2 environment (Fahey et al. 2008 citing Jonsson et al. 2004). This is supported by a recent study that used a chemistry-climate model to simulate changes in ozone observed over the past century and found the rate of ozone loss reduced in the upper stratosphere due to cooling temperatures (Reader et al. 2013).

In the lower stratosphere, where transport plays an important role both within the stratosphere and between the troposphere and stratosphere, cooling temperatures have less influence on ozone concentrations (except in the polar regions). Since 1993, ozone in the lower stratosphere above the Arctic has been greatly affected by cooling temperatures, as cooling has led to an increase in polar stratospheric clouds (Fahey et al. 2008). Polar stratospheric clouds play a significant role in reducing ozone concentrations. Ozone in the lower stratosphere above the Antarctic does not demonstrate such a significant response to cooling temperatures because this region already experiences temperatures cold enough to produce these clouds.

particularly susceptible to ozone loss due to a combination of atmospheric circulation patterns, and the buildup of ozone-depletion precursors during the dark winter months from June to September.

5.5.2.9.3 Circulation and Transport Patterns

The large-scale Brewer-Dobson circulation represents the transport between the troposphere and stratosphere: an upward flux of air from the troposphere to the stratosphere occurs in the tropics balanced by a downward flux of air in the extratropics. This circulation carries stratospheric ozone from the tropics poleward. Over the past century, it was been suggested that the ozone in the lower stratosphere has experienced an acceleration in this transport, particularly in the northern hemisphere—potentially explaining the larger increase in total atmospheric ozone per area (i.e., column ozone) observed in the northern hemisphere compared to the southern hemisphere (Reader et al. 2013).

Models suggest that the reduction of ozone above Antarctica is responsible for strengthening the circulation of stratospheric circumpolar winds of the wintertime vortex (i.e., the establishment of the vortex leads to significant ozone loss in late winter/early spring) (Fahey et al. 2008 citing Gillet and Thompson 2003, and Thompson and Solomon 2002).[55] Observations have shown that these winds can extend through the troposphere to the surface, leading to cooling over most of Antarctica. These studies suggest changes in stratospheric ozone can affect surface climate parameters.

5.5.2.9.4 Trends and Projections

Observations of global ozone concentrations in the upper stratosphere have shown a strong and statistically significant decline of approximately 6 to 8 percent per decade from 1979 to the mid-1990s, and a near zero or slightly positive trend thereafter (WMO 2011). Observations of global ozone within the lower stratosphere demonstrate a slightly smaller but statistically significant decline of approximately 4 to 5 percent per decade from 1979 to the mid-1990s (WMO 2011). The depletion of stratospheric ozone has been estimated to cause a slight radiative cooling of approximately -0.05 watts per square meter with a range of -0.15 to 0.05 watts per square meter, although there is great uncertainty in this estimate (Ravishankara et al. 2008).

The WMO (2011) used 17 coupled chemistry-climate models to assess how total column ozone (i.e., the total ozone within a column of air from Earth's surface to the top of the atmosphere) and stratospheric ozone will change in response to climate change and reductions in ozone-depleting substances. Under a moderate (A1B) emissions scenario, the model ensemble suggests changes in climate will accelerate the recovery of total column ozone. Projected ozone concentrations are compared to 1980 baseline conditions. Significant ozone reduction occurred between 1980 and approximately 2000. The model ensemble suggests the northern mid-latitudes total column ozone will recover to 1980 levels between 2015 and 2030, and the southern mid-latitudes total column ozone will recover between 2030 and 2040. Overall, the recovery of total ozone in the mid-latitudes to 1980 levels is projected to occur 10 to 30 years earlier as a result of climate change. The Arctic has a similar recovery time to 1980 conditions, while the Antarctic will regain 1980 concentrations around mid-century (because the chemistry-climate models underestimate present-day Arctic ozone loss, the modeled Arctic recovery period might be optimistic). The recovery is linked to impacts of climate that affect total column ozone, including (1) increased formation of ozone in the mid-to-upper stratosphere in response to cooling temperatures, (2) accelerated ground-level ozone formation in the troposphere as it warms, and (3) an accelerated

[55] During the polar winter, a giant vortex with wind speeds exceeding 300 kilometers (186 miles) per hour can establish above the South Pole, acting like a barrier that accumulates ozone-depleting substances. In Antarctic springtime, temperatures begin to warm and the vortex dissipates. The ozone-depleting substances, now exposed to sunlight, release large amounts of reactive molecules that significantly reduce ozone concentrations (Fahey and Hegglin 2011).

Brewer-Dobson circulation increase in ozone transport in the lower stratosphere from the tropics to the mid-latitudes (WMO 2011).

In another study, doubled CO_2 concentrations simulated by 14 climate-change models project a 2 percent increase per decade in the annual mean troposphere-to-stratosphere exchange rate. This acceleration could affect long-lived gases such as CFCs, CH_4, and N_2O by reducing their lifetime and increasing their removal from the atmosphere. In addition, this could increase the vertical transport of ozone concentrations from the stratosphere to the troposphere over mid-latitude and polar regions (Fahey et al. 2008 citing Butchart and Scaife 2001).

5.5.2.10 Tipping Points and Abrupt Climate Change

"Tipping points" refer to thresholds within Earth systems that could be triggered by continued increases in the atmospheric concentration of GHGs, incremental increases in temperature, or other relatively small or gradual changes related to climate change.[56] Earth systems that contain a tipping point exhibit large or accelerating changes or transitions to a new physical state, which are significantly different than the rates of change or states that have been exhibited in the past, when the tipping point is crossed. Examples of tipping points in Earth systems include rapid melting or permanent loss of Arctic sea ice, the Greenland ice sheet, and the West Antarctic ice sheet; slowing of the Atlantic Meridional Overturning Circulation (AMOC); changes in the behavior of the El Niño-Southern Oscillation (ENSO); changes in the Indian summer monsoon or the West African monsoon; increased forest dieback in the Amazonian rainforest; die-off events in boreal forests; rapid releases of CH_4 to the atmosphere from undersea hydrates or melting permafrost; and large-scale changes in precipitation and the hydrologic cycle.

5.5.2.10.1 Atlantic Meridional Overturning Circulation

The AMOC is the northward flow of warm, salty water in the upper layers of the Atlantic Ocean coupled to the southward flow of colder water in the deep layers, and transports oceanic heat from low to high latitudes.

The term thermohaline circulation (THC) refers to the physical driving mechanism of ocean circulation, resulting from fluxes of heat and freshwater across the sea surface, subsequent interior mixing of heat and salt, and geothermal heat sources. The AMOC discussed in the IPCC reports is the observed response in the Atlantic Ocean basin to this type of ocean circulation coupled with wind-driven currents.

If enough freshwater enters the North Atlantic (such as from melting sea ice or the Greenland ice sheet), the density-driven sinking of North Atlantic waters might be reduced or even stopped, as apparently occurred during the last glacial cycle (Lenton et al. 2008 citing Stocker and Wright 1991). This would likely reduce the northward flow of thermal energy in the Gulf Stream and result in less heat transport to the North Atlantic. At the same time, reduced formation of very cold water would likely slow the global ocean THC, leading to impacts on global climate and ocean currents.

[56] In the 2013 report, *Abrupt Impacts of Climate Change*, NRC also included a discussion on abrupt changes in physical, biological, and human systems that result from gradual climate change (referred to as "abrupt climate impacts", as opposed to "abrupt climate changes"). The discussion in this section remains focused on abrupt climate changes, while the effect of abrupt impacts is discussed further in separate sub-sections of Section 5.1.

It is *very likely* that the AMOC will weaken over the 21st century;[57] it is *likely* that there will be some decline in the AMOC by about 2050, but there could be some decades when the AMOC increases due to large natural internal variability (IPCC 2013a). It is *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century (for the scenarios considered); and that there is *low confidence* in assessing the evolution of the AMOC beyond the 21st century because of the limited number of analyses and equivocal results (IPCC 2013a). However, the SPM concludes that a collapse beyond the 21st century for large sustained warming cannot be excluded.

This finding is supported by an NRC synthesis study of recent information on tipping points and abrupt climate change. The study committee found that the AMOC is likely to remain stable to disturbances and that an abrupt change or shut down will not occur in this century. The report acknowledged the importance of ongoing monitoring to identify whether slow changes in the AMOC have important effects, and to better understand the slight possibility of a major event occurring, such as shut down of the AMOC (NRC 2013).

5.5.2.10.2 Greenland and West Antarctic Ice Sheets

The sustained mass loss by ice sheets would cause large sea-level rise, and some part of the mass loss might be irreversible (IPCC 2013a). For example, there is *high confidence* that sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea-level rise of up to 7 meters (29 feet). Current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) global mean warming with respect to pre-industrial.

Of particular concern is the potential for abrupt increases in sea-level rise from rapid destabilization and ice loss from glaciers with bases in deep water. For these glaciers, warming oceans erode the base and cause the ice to float, accelerating losses. In Greenland, most areas of deep water contact between ice sheets and the ocean are limited to narrow troughs where the ice is less likely to flow rapidly into ocean basins, so the likelihood of rapid destabilization during this century is low (NRC 2013).

Abrupt and irreversible ice loss from a potential instability of marine-based (as opposed to land-based) sectors of the Antarctic ice sheet (i.e., ice shelves) in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment (IPCC 2013a; NRC 2013; Hansen et al. 2013). That said, two recent studies (Joughin et al. 2014, Rignot et al. 2014) published since the IPCC (2013b) assessment report indicate that these Western Antarctic ice shelves have been accelerating their melt in recent decades, that this increase is projected to continue, and that there is little in the regional geography to stop them from an eventual full decline (i.e., an irreversible collapse) as they retreat into deeper water.

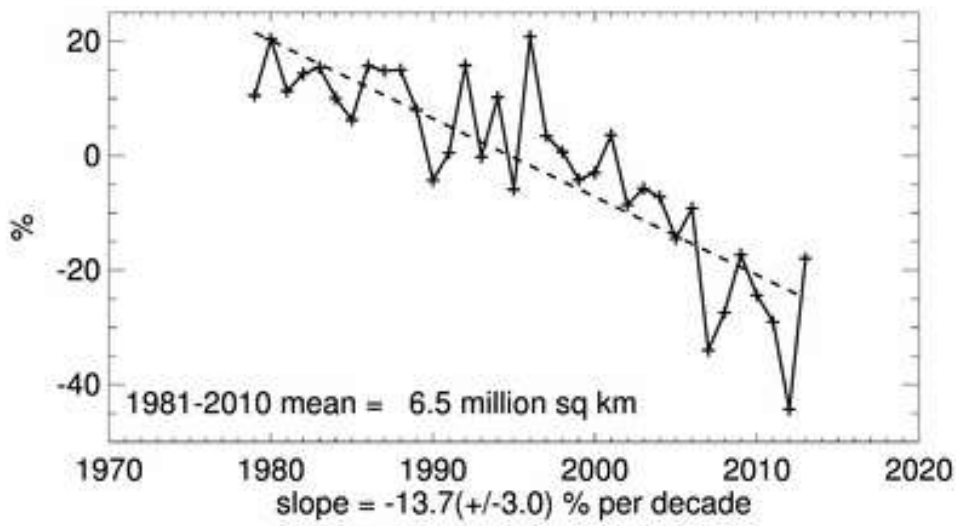
A recent study by Mengel and Levermann (2014) demonstrated the potential irreversibility of marine-based ice sheet loss and the presence of thresholds beyond which ice loss becomes self-sustaining. In a study of ice in the Wilkes Basin of East Antarctica (as opposed to West Antarctic ice sheets, which have been studied in more detail), the authors found that the loss of a relatively small volume of ice in a seaward region of the shelf (dubbed the "ice plug" by the authors) would lead to an irreversible disintegration of the entire regional ice sheet. There is no short-term threat of ice loss from the Wilkes Bay ice sheet, as the study looked at scenarios of 400 to 800 years with ocean temperatures 1 to 2.5°C (1.8 to 4.5°F) warmer than current conditions.

[57] Best estimates and ranges for the AMOC reduction are 11 percent (1 to 24 percent) in the lowest (RCP2.6) scenario and 34 percent (12 to 54 percent) in the highest (RCP8.5) scenario (IPCC 2013b).

5.5.2.10.3 Arctic Sea Ice

Since satellite observations of Arctic sea ice began in 1978, a significant decline in the extent of summer sea ice[58] has been observed, with the record minimum extent—a decrease of more than 40 percent in September, i.e., the month when the minimum in the sea-ice extent typically occurs—recorded in 2012 (*see* Figure 5.5.2-2) (GCRP 2014 citing NSIDC 2012). There is robust evidence that the downward trend in Arctic summer sea-ice extent since 1979 is now reproduced by more models than at the time of the AR4, with about one-quarter of the models showing a trend as large as, or larger than, the trend in the observations. Most models simulate a small downward trend in Antarctic sea-ice extent, albeit with large inter-model spread, in contrast to the small upward trend in observations (IPCC 2013a). The IPCC (2013a) suggests that anthropogenic influences have *very likely* contributed to these Arctic sea ice loss since 1979, and that it is *very likely* that the Arctic sea ice cover will continue to shrink and thin.

Figure 5.5.2-2. Northern Hemisphere Extent Anomalies[a,b]



[a] Source: GCRP 2014 citing NSIDC 2014.

[b] Monthly ice extent anomalies plotted as a time series of percent difference between the extent for September and the mean for September based on the January 1981 to December 2010 data. The anomaly data points are plotted as plus signs and the trend line is plotted with a dashed gray line.

Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea with this loss of ice expected to continue. Arctic sea-ice extent increases during the cold winter and decreases during the warmer summer. The Arctic Ocean is expected to become essentially ice free in summer before mid-century under future scenarios that assume continued growth in global emissions, although sea ice would still form in winter (GCRP 2012 citing Stroeve et al. 2012 and Wang and Overland 2009; NRC 2013). Year-round reductions in Arctic sea-ice extent are projected by the end of the 21st century from multi-model averages. These reductions range from 43 percent for the lower (RCP2.6) scenario to 94 percent for the higher (RCP8.5) scenario in September and from 8 percent for the lower (RCP2.6) scenario to 34 percent for the higher (RCP8.5) scenario in February (*medium confidence*) (IPCC 2013a).

[58] The September sea-ice extent is typically considered the annual minimum in ice extent. It should be noted that discussion of the September sea-ice extent (or late summer sea-ice extent) is simply one metric of the impact of sea ice on climate, and vice versa. For example, the loss of sea ice can have impacts on regional climate during subsequent months (e.g., thinner ice and ice-free areas in the fall and winter allow for more heat to be transferred from the ocean to the atmosphere) and in future years (e.g., thinner or less ice in one season could contribute to thinner or less ice in a following season).

Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea-ice extent, a nearly ice-free Arctic Ocean in September before mid-century is *likely* for the higher (RCP8.5) scenario (*medium confidence*). A projection of when the Arctic might become nearly ice free in September in the 21st century cannot be made with confidence for the other scenarios (IPCC 2013a).

Larger areas of open water in the Arctic during the summer will affect the Arctic climate, ecosystems, and human activities in the North; these effects on the Arctic could potentially be large and irreversible. Less summer ice may disrupt the marine food cycle, alter the habitat of certain marine mammals, and exacerbate coastline erosion. Reductions in summer sea ice will also increase the navigability of Arctic waters, opening up opportunities for shipping and economic activities, but also creating new political and legal challenges among circumpolar nations (NRC 2013).

5.5.2.10.4 Irreversibility of Anthropogenic Climate Change Resulting From CO_2 Emissions

A large fraction of anthropogenic climate change resulting from CO_2 emissions (e.g., global mean temperature increase, and ocean acidification increase) is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period (IPCC 2013a). Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Due to the long time scales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40 percent of emitted CO_2 will remain in the atmosphere longer than 1,000 years (IPCC 2013b). In addition, the following impacts have been estimated per 1°C (1.8°F) of global warming: 5 to 10 percent change in precipitation for a number of regions, 3 to 10 percent increase in heavy rainfall, 5 to 15 percent yield reductions of a number of crops, and 5 to 10 percent change in streamflow in many river basins worldwide (NRC 2011).

5.5.2.10.5 Increases in the Risk of Extinction for Marine and Terrestrial Species

The rate of climate change is increasing the risk of extinction for a number of marine and terrestrial species (NRC 2013). Climate change can cause abrupt and irreversible extinctions through four known mechanisms (NRC 2013):

- Direct impacts from an abrupt event, such as flooding of an ecosystem through a combination of storm surge and sea-level rise.
- Incremental climatic changes that exceed a threshold beyond which a species enters decline, for example, pikas and ocean coral populations are close to physiological thermal limits.
- Adding stress to species in addition to non-climatic pressures such as habitat fragmentation, overharvesting, and eutrophication.
- Biotic interactions, such as increases in disease or pests, loss of partner species that support a different species, or disruptions in foodwebs after the decline of a keystone species.

It is very likely that some species will become extinct or fall below viable numbers in the next few decades (NRC 2013). Vulnerable species include species whose tolerance to climate parameters will be exceeded by climate change, species whose processes of growth, reproduction, or survival will be affected by climate change (including biotic interactions), and species trapped by habitat fragmentation in areas that will become unsuitable (NRC 2013). Based on the current state of scientific knowledge, *Abrupt Climate Change Impacts* (NRC 2013) concluded that there is a "plausible" risk that already-elevated extinction rates will be accelerated further by climate change. The outcome would be a loss of

"many more" species over the next few decades than would occur without climate change, although it is not possible to develop exact probabilities of the added contribution of climate change to extinction risk (NRC 2013).

5.5.2.10.6 Additional Tipping Points

There is no clear scientific consensus at this time as to whether major tipping points, other than loss of the Arctic sea ice in summer and increases in the risk of extinction of marine and terrestrial species, will be reached during this century (GCRP 2014, NRC 2013). The *National Climate Assessment* (GCRP 2014) and *Abrupt Impacts of Climate Change* (NRC 2013) indicate a number of potential tipping points (*see* Figure 5.5.2-3) including:

- Arctic sea ice (*see* above)
- Greenland ice sheet (*see* above)
- West Antarctic ice sheet (*see* above)
- El-Niño-Southern Oscillation (ENSO)
- Indian summer monsoon
- West African monsoon
- Amazon rainforest
- Boreal forest
- Atlantic Meridional Overturning Circulation (AMOC) (*see* above)
- Release of methane hydrates and permafrost and tundra loss

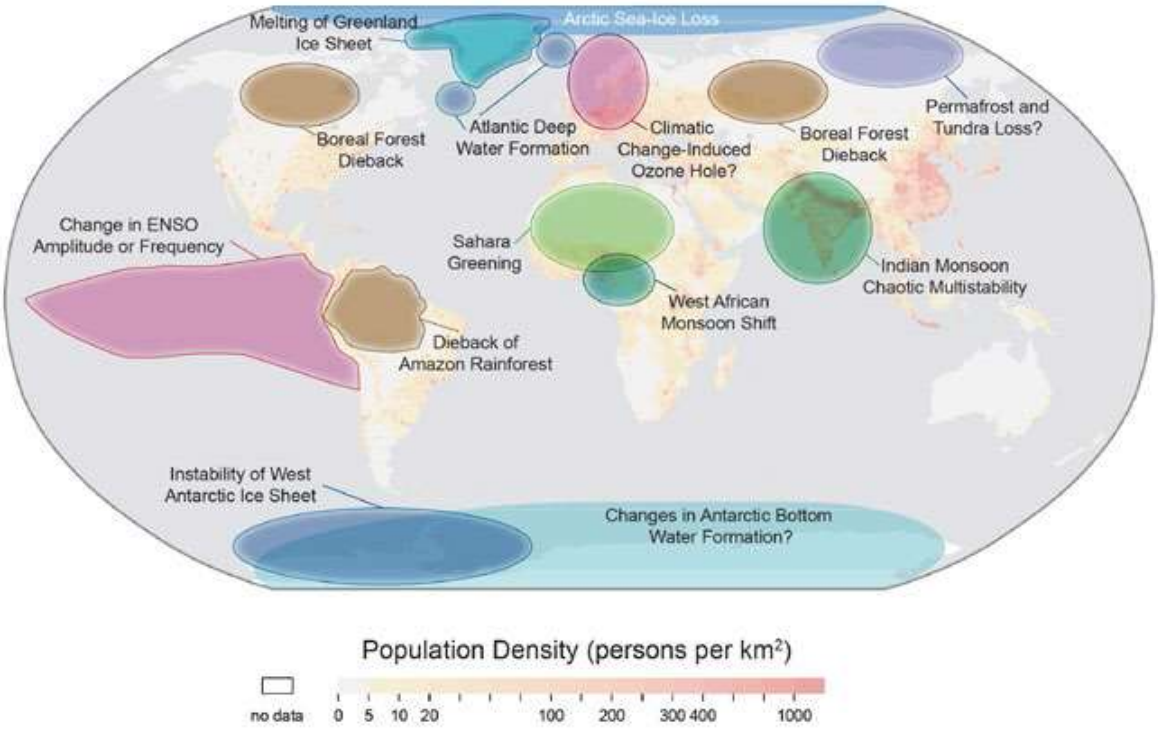
El-Niño-Southern Oscillation (ENSO).[59] The changes that might lead to increasingly persistent (and frequent) El Niño (or La Niña) conditions are particularly uncertain. Increases in ocean heat content could have an impact on ENSO conditions, but predictive and paleoclimate modeling studies do not agree on the magnitude, frequency, and direction of these impacts. However, ENSO has substantial and large-scale impacts on the global climate system (Lenton et al. 2008).[60]

Indian Summer Monsoon. The Indian summer monsoon is the result of land-to-ocean pressure gradients and advection of moisture from ocean to land. By warming the land more than the ocean, climate change generally strengthens the monsoon. However, reductions in the amount of solar radiation that is absorbed by the land surface, due to some types of land use change, generally weaken it. An albedo greater than roughly 50 percent is necessary to simulate the collapse of the Indian summer monsoon in a simple model (Lenton et al. 2008 citing Zickfeld et al. 2005). IPCC projections do not project passing a threshold this century, although paleoclimatic reconstructions do indicate that the monsoon has changed substantially in the past (Lenton et al. 2008).

[59] ENSO describes the full range of the Southern Oscillation (see-saw of atmospheric mass or pressure between the Pacific and Indo–Australian regions) that includes both sea-surface temperature increases and decreases compared to the long-term average. El Niño is the warm phase of ENSO, in which sea surface temperatures along the central and eastern equatorial Pacific are warmer than normal, while La Niña is the cold phase of ENSO.

[60] ENSO influences patterns of tropical sea surface temperature, and has been implicated in historical episodes of extreme drought, including the "mega-droughts" (900 to 1600 AD).

Figure 5.5.2-3. Potential Tipping Points[a,b]



[a] Source: GCRP 2014 adapted from Lenton et al. 2008.

[b] Stylized map of potential policy-relevant tipping elements in the Earth's climate system overlain on population density. Question marks indicate systems whose status as tipping elements is particularly uncertain.

West African Monsoon. Sahara/Sahel rainfall depends on the West African monsoon circulation, which is affected by sea-surface temperature. By warming the land more than the ocean and therefore causing greater upward movement of the air, GHG forcing is expected to draw more moist oceanic air inland and thereby increase rainfall in the region, which is simulated by some models. Other models, however, project a less productive monsoon. The reasons for this inconsistency are not clear (Lenton et al. 2008).

Amazon Rainforest. The recycling of precipitation in the Amazon rainforest implies that deforestation, reductions in precipitation, a longer dry season, and increased summer temperature could contribute to forest dieback. These conditions are thought to be linked to a more persistent El Niño and an increase of global average temperature by 3 to 4°C (5.4 to 7.2°F). Important additional stressors also present include forest fires and human activity (such as land clearing). A critical threshold might exist in canopy cover, which could be reached through changes in land use or regional precipitation, ENSO variability, and global radiative forcing (Lenton et al. 2008).

Boreal Forest. The dieback of boreal forest could result from a combination of increased heat stress and water stress, leading to decreased reproduction rates, increased disease vulnerability, and subsequent fire. Although highly uncertain, studies suggest a global warming of 3°C (5.4°F) could be the threshold for loss of the boreal forest (Lenton et al. 2008).

Release of Methane Hydrates and Permafrost and Tundra Loss. A "catastrophic" release of methane to the atmosphere from clathrate hydrates[61] in the sea bed and permafrost, and from northern high-latitude and tropical wetlands, has been identified as a potential cause of abrupt climate change (EPA 2009, Hansen et al. 2013). Clark et al. (2008) state that the size of the hydrate reservoir is uncertain (perhaps by up to a factor of 10), making judgments about risk difficult to assess (EPA 2009).

This uncertainty is borne out by a study by Tanocai et al. (2009) estimating soil organic carbon pools in the northern circumpolar permafrost regions. The study reports new estimates —including deeper layers and pools not previously accounted for—about double those reported in previous analyses for the first meter of soil. Hansen et al. (2013), while recognizing that the risk of triggering rapid methane hydrate or permafrost emissions is largely unquantified, observed that hydrates under shallow waters are most vulnerable to release. Larger deposits in deep sediments are likely to remain stable for millennia. The timescale for release of methane and CO_2 emissions from terrestrial permafrost in response to warming is between a few decades and several centuries if warming continues (Hansen et al. 2013).

The outlook for an abrupt, irreversible release of CO_2 and methane from terrestrial permafrost and methane hydrates in this century is judged to be low, with a moderate risk of significant change in the stability of methane hydrates and a high risk for terrestrial permafrost after 2100 (NRC 2013). An abrupt release of these stocks could contribute to sudden, dramatic warming in the atmosphere; it is possible, for example, that sudden releases from methane hydrates and frozen soils have contributed to "hyper thermals" or sudden spikes in global warming that have occurred alongside slower, gradual warming trends in the past (Hansen et al. 2013).

To the degree that the action in this rulemaking reduces the rate of CO_2 emissions, the rule contributes to the general reduction or delay of reaching these tipping-point thresholds. Moreover, while the Proposed Action alone does not produce sufficient CO_2 emissions reductions to avoid reaching these tipping-point thresholds, it is one of several other federal programs, which, in conjunction with NHTSA CAFE standards, could make substantial contributions in averting levels of abrupt and severe climate change. These conclusions are not meant to be read as expressing NHTSA views that tipping points in climate-related systems are not areas of concern for policymakers. Under NEPA, the agency is obligated to discuss "the environmental impact[s] *of the proposed action*." 42 U.S.C. § 4332(2)(C)(i) (emphasis added). The discussion above fulfills NHTSA's NEPA obligations regarding this issue.

5.5.3 Regional Impacts of Climate Change

This section discusses the regional impacts of climate change in the United States and is a supplement to the discussions of sectoral impacts provided previously. Specifically, Sections 5.5.2.1 through 5.5.2.8 address cumulative impacts on key natural and human resources by region (Northeast, Southeast and the Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, and the Islands [i.e., Hawaii and the U.S. affiliated Pacific Islands]). In addition, a section discussing impacts on indigenous peoples is provided. Each section begins with a brief description of observed and projected environmental change and then discusses impacts on the following sectors: freshwater resources; ocean systems, coastal, and

[61] Clathrate hydrates are "inclusion compounds" in which a hydrogen-bonded water framework—the host lattice—traps "guest" molecules (typically gases) within ice cages. Naturally occurring gas hydrate on Earth is primarily methane hydrate and forms under high pressure–low temperature conditions in the presence of sufficient methane. These conditions are most often found in relatively shallow marine sediments on continental margins, but also in some high-latitude terrestrial sediments (permafrost). Although the amount of methane stored as hydrate in geological reservoirs is not well quantified, it is very likely that very large amounts are sequestered in comparison to the present total atmospheric methane burden (Brook et al. 2008).

low-lying areas; food, fiber, and forest products; terrestrial and freshwater ecosystems; urban areas; rural areas; human health; and human security.

Although this section does not present specific examples of adaptation to climate impacts in each region or sector, adaptation is occurring at local, state, and regional scales. A number of organizations, state agencies, and planning bodies are considering adaptation options in response to climate change and climate variability. Across resources and regions, the process of incorporating adaptation into decisionmaking varies according to, for example, the awareness, frequency and severity of the climate change impacts. For some examples of general adaptation efforts at varying geographic scales, *see* the adaptation sections in each resource-sector discussion in Section 5.5.1.

5.5.3.1 Northeast

This section discusses climate change impacts in the Northeast region of the United States, which includes the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

The Northeast is vulnerable to a variety of climate change impacts, including increasing temperatures, shorter snow seasons, more frequent heat waves, sea-level rise, drought, coastal and riverine flooding, and intense precipitation events. Climate change is projected to exacerbate each of these impacts, which can result in changes to the area's economy, landscape, and quality of life (GCRP 2014). In particular, the Northeast is vulnerable to impacts on human health; food, fiber, and forest products; ocean systems, coastal, and low-lying areas; urban areas; and rural areas.

5.5.3.1.1 Observed and Projected Changes in Exposure

Increasing temperatures have already had wide-ranging impacts on the Northeast. Between 1895 and 2011, the annual average temperature in the Northeast has risen almost 2.0°F at an average rate of nearly 0.16°F per decade (GCRP 2014 citing Kunkel et al. 2013). Winter temperatures have risen 50 percent faster than the annual average, at nearly 0.24°F per decade over the same time period (Kunkel et al. 2013).

Temperatures are projected to continue to rise. By the 2080s, Northeast temperatures are projected to increase by 4.5 to 10°F under the higher (A2) emissions scenario, and 3 to 6°F under the lower (B1) emissions scenario, relative to the 1971 to 1999 period (GCRP 2014 citing Kunkel et al. 2013). The frequency, intensity, and duration of heat waves is projected to increase under both emissions scenarios, with the greatest increase seen under the higher (A2) emissions scenario (GCRP 2014). Conversely, the frequency, intensity, and duration of cold air outbreaks is expected to decrease throughout the century; although a loss of Arctic sea ice could dilute this effect by affecting the jet stream and mid-latitude weather patterns (GCRP citing Francis and Vavrus 2012, Liu et al. 2012). The southern portion of the Northeastern region, including Maryland, Delaware, and southwestern West Virginia and New Jersey is projected to experience an additional 60 days per year above 90°F under the higher (A2) emissions scenario, relative to the 1971 to 2000 mean (GCRP 2014).

Precipitation has increased by approximately 5 inches (more than 10 percent) at a rate of 0.4 inches per decade (GCRP 2014 citing Kunkel et al. 2013), from 1895 to 2011. Fall precipitation also exhibited a statistically significant increase of 0.24 inches per decade over the same time period, while spring, summer, and winter increases are not statistically significant (Kunkel et al. 2013). Future changes in precipitation exhibit greater uncertainty than temperature projections (GCRP 2014 citing Kunkel et al. 2013). Winter and spring precipitation is, however, projected to increase in some parts of the Northeast such as the northern part of the region (GCRP 2014). Averaged across the Northeastern region, models

project between a 5 and 20 percent increase (at the 25th and 75th percentiles, respectively) in winter precipitation under the higher (A2) emissions scenario, relative to a 1971 to 1999 mean. For the same time period and emissions scenarios, summer and fall precipitation are projected to increase by only a small amount when compared to natural variations (GCRP 2014 citing Kunkel et al. 2013, Karl et al. 2009). In addition to an increase in heavy rainfall events, winter precipitation is expected to fall increasingly as rain, rather than snow (EPA 2009).

Extreme precipitation in the Northeast, defined as the amount of precipitation falling in the heaviest 1 percent of all daily events, has increased by more than 70 percent between 1958 and 2010 (GCRP citing Groisman et al. 2013). The frequency of heavy downpours is expected to continue its upward trend throughout the century. At the same time, the risk of droughts in the summer and fall is expected to increase due to higher evaporation rates and earlier winter and spring snowmelt (GCRP citing NPCC 2010). Coastal flooding in the Northeast has increased due to sea-level rise of nearly 1 foot since 1900 (GCRP 2014). In Philadelphia, for example, sea level rose 1.2 feet from 1901 to 2012 (GCRP 2014 citing NOAA 2013). Sea-level rise in the Northeast has outpaced the global average sea-level rise of 8 inches over the same time period, primarily because of land subsidence (GCRP 2014 citing Church et al. 2010). Recent research suggests that a weakening of the Gulf Stream may also play a role (GCRP 2014 citing Sallenger et al. 2012).

Global sea levels are projected to rise between 1 and 4 feet by 2100 relative to 1992 (GCRP 2014 citing Parris et al. 2012). Just as sea-level rise in the Northeast during the last century exceeded global sea-level rise, so too it is expected that future sea-level rise in the Northeast will outpace global sea-level rise. This phenomenon would be exacerbated if the Gulf Stream were to weaken (GRCP citing Sallenger et al. 2012, Yin et al. 2009). Today's storm events occurring at a sea-level rise of 2 feet would more than triple the frequency of dangerous coastal flooding across much of the Northeast (GCRP citing Horton et al. 2011). In the New York City Battery area, for example, there is a flood event of a certain magnitude that, from a baseline period 2000 to 2004, had a 1 percent chance of occurring or being exceeded each year. By 2050, the probability of a flood event of that same magnitude occurring or being exceeded each year increases to between 1.4 and 5 percent (this range represents the 10th and 90th percentile of 35 different climate model runs, each of which used the RCP4.5 [lower] and RCP8.5 [higher] emissions scenarios) (New York City Panel on Climate Change 2013). Such extreme storm events cause excess mortality and morbidity along the East Coast of the United States (IPCC 2014c).

Table 5.5.3-1 summarizes the projected trends for climate variables in the Northeast and the associated resources the trends will affect.

Table 5.5.3-1. Observed and Projected Trends in Environmental Variables for the Northeast

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Increase in temperature of 2 ˚F (0.16 ˚F per decade) between 1895 and 2011; more pronounced warming during the winter and spring; increase in freeze-free season.	Increase in annual average temperatures with shorter, warmer winters and longer growing seasons; increase in number of days above 95˚F throughout the region.	▪ Food, fiber, and forest products ▪ Urban areas ▪ Rural areas ▪ Human health
Precipitation	Increase in precipitation of 5 inches (0.4 inches per decade), or 10% between 1895 and 2011; 70% increase in heavy precipitation events.	Increase in annual precipitation; decrease in summer precipitation and an increase in winter precipitation; increase in frequency of seasonal droughts; decrease in length of snow season; increase in number of wet days.	▪ Freshwater resources ▪ Urban areas ▪ Rural areas
Sea level	Approximately 1 foot increase (1.2 inches per decade) in sea levels since 1900.	Increase in sea levels greater than global average, which is projected to rise between 1 and 4 feet by 2100.	▪ Ocean systems, coastal, and low-lying areas ▪ Urban areas ▪ Rural areas ▪ Human health

Notes:

Sources: GCRP 2014, Kunkel et al. 2013.

5.5.3.1.2 Freshwater Resources

Changes to freshwater resources are already occurring in the Northeast. For example, earlier snowmelt has caused the flow of rivers and streams in New England to peak earlier in the season, which affects both aquatic organisms and water supply management (Kunkel et al. 2013). Snow depth has additionally experienced a decline in recent decades. For example, 18 of 23 snow areas surveyed in Maine decreased in depth, with mountainous sites along the Maine–New Hampshire border showing a decrease of 16 percent from 1926 to 2004 (Kunkel et al. 2013 citing Hodgkins and Dudley 2006).

Sea-level rise is projected to increase saltwater infiltration into freshwater distribution systems (GCRP 2014 citing NPCC 2010). In New York City, coastal wetlands will be lost as sea-level rises, as coastal development prevents wetlands from naturally moving inland (IPCC 2014b citing Gaffin et al. 2012). As much as 21 percent of the U.S. mid-Atlantic coastal wetlands are potentially at risk of inundation between 2000 and 2100 (EPA 2009). Coastal wetlands already experiencing submergence are *virtually certain* to continue to shrink due to accelerated sea-level rise, among other climate- and non-climate-related factors (EPA 2009).

Increased eutrophication due to warming water temperatures will incur costs related to the upgrading of municipal drinking water treatment facilities and purchase of bottled water. Additionally, sea-level rise poses an additional risk to water treatment facilities. EPA has identified more than $200 billion in wastewater management infrastructure in need of upgrading to protect from nutrient pollution (Baron et al. 2013 citing EPA 2011).

5.5.3.1.3 Terrestrial and Freshwater Ecosystems

Ecosystems in the Northeast region have already experienced a number of negative impacts from climate change. For example, species have been observed in the Green Mountains of Vermont moving upslope (GCRP 2014 citing Beckage et al. 2008), certain flowers are blooming earlier (GCRP 2014 citing Primack et al. 2004), and migratory birds are arriving sooner (GCRP 2014 citing Butler 2003). Species that find difficulty in adjusting to changes in migration patterns or food availability are increasingly vulnerable to the impacts of climate change (GCRP 2014). For example, while some bird and insect species have been able to expand their range to the north, hemlock trees have been unable to resist invasive insects and have experienced a reduction in population.

Rising air and ocean temperatures can also negatively affect Northeastern ecosystems. Warmer winter temperatures, coupled with less snowfall, have benefitted deer, which degrade forest vegetation (GCRP 2014 citing Stromayer and Warren 1997). Increasing ocean temperatures are projected to shift the range of economically important marine species northward, such as cod and lobster. This could cause significant declines in fisheries south of Cape Cod (GCRP 2014 citing Fogarty et al. 2008, Frumhoff et al. 2007). While fish species adapted to cold water could decline and those adapted to warm water could increase as ocean temperatures increase, there remains considerable uncertainty over the ability of those species to adapt to shifts in climate zones. Similarly, while hardwood trees in the Northeast region are projected to benefit from increased concentrations of CO_2, this productivity increase could be offset by summer drought and other impacts of climate change (GCRP 2014 citing Mohan et al. 2009). Climate change is also projected to increase populations of insect pests, pathogens, and invasive plants that reduce biodiversity, function, and resilience of Northeastern ecosystems.

5.5.3.1.4 Ocean Systems, Coastal, and Low-Lying Areas

The Northeast includes densely populated coastal areas that are extremely vulnerable to projected increases in the extent and frequency of storm surge, coastal flooding, sea-level rise, property damage, and loss of wetlands (GCRP 2014). The region has already felt the impact of coastal flooding and property damage. Hurricane Irene caused New York City to close its mass transit system and authorities ordered the mandatory evacuation of 2.3 million coastal residents (GCRP 2014); New York City is one of two U.S. cities projected to be among the top 20 cities worldwide in terms of population exposed to coastal flooding (Hanson et al. 2011).

As much as 21 percent of the U.S. mid-Atlantic coastal wetlands are potentially at risk of inundation between 2000 and 2100, and coastal wetlands already experiencing submergence are "*virtually certain*" to continue to shrink due to accelerated sea-level rise, among other climate- and non-climate-related factors (EPA 2009). In addition, melting of the Greenland ice sheet could have an effect on ocean circulation and sea-level rise dynamics, which might exacerbate sea-level rise experienced on the northeastern coast of the United States and in Canada (Hu et al. 2009a).

Climate change is projected to further affect urban and rural areas throughout the Northeast. A sea-level rise of 2 feet, which is toward the lower end of global projections (between 1 and 4 feet by 2100 relative to 1992 levels), would flood or render unusable 212 miles of roadway, 77 miles of rail, 3,647 acres of airport facilities, and 539 acres of runways absent any adaptation investment (GCRP 2014 citing DOT 2008). In Maryland, 2 feet of sea-level rise would flood 32 percent of port facilities, which generate over 50,000 jobs and $3.6 billion in personal income (based on 2006 values) (GCRP 2014 citing Maryland Port Administration 2008). States in the southern portion of the Northeast, such as Delaware and Maryland, are projected to face greater impacts from sea-level rise than northern states due to a higher rate of sea-level rise and flat coastlines (GCRP 2014). However, the northern states are not exempt from

impacts; low-lying areas in Boston could face up to $94 billion in building damage and emergency response costs from 2000 to 2100 depending on sea-level rise and adaptation actions (GCRP 2014 citing Kirshen et al. 2008).

More generally, sea-level rise and an increase in frequency and intensity of coastal flooding would affect communications, energy, transportation, and water and waste infrastructure in the coming century. Impacts include damage to communications equipment in low-lying areas; inundation of coastal power plants; flooding of streets, subways, bridges, and tunnels; and release of pollution and contaminant runoff from sewer systems.

5.5.3.1.5 Food, Fiber, and Forest Products

Farmers in the Northeast region are already witnessing the impacts of climate change. Intense precipitation events, which have increased by more than 70 percent between 1958 and 2010, have damaged crops. Wet spring seasons have delayed grain and vegetable planting in regions such as New York, which delays harvest dates and reduces yields (GCRP 2014). Counterintuitively, frost damage has actually increased over the past decade because crops that soften due to winter warm spells are increasingly susceptible to subsequent freeze damage (GCRP 2014).

Weed and pest prevalence, which could increase as growing seasons lengthen and winters warm, pose further risks to crops. The Northeast region has already observed earlier arrivals and increased populations of some pests, such as corn earworm (GCRP 2014 citing Wolfe et al. 2008). Additionally, certain aggressive weeds such as kudzu benefit disproportionally from increased atmospheric CO_2 concentrations. Weed-killers could lose efficacy on weeds grown under higher atmospheric CO_2 concentrations (GCRP 2014 citing Ziska et al. 1999). All of the competition studies that compare the photosynthetic pathway for both weeds and crops have concluded that weed growth will benefit more than crop growth (GCRP 2014 citing Ziska and Runion 2007). Finally, as summer temperatures rise, growing seasons lengthen, and heat stress increases, farmers could face water shortages to meet demand (GCRP 2014 citing Hayhoe et al. 2007, Wolfe et al. 2011).

5.5.3.1.6 Urban Areas and Rural Areas

Sea-level rise, increases in frequency and intensity of coastal flooding, and extreme precipitation events pose a risk to urban and rural areas alike. During the summer of 2011, Hurricane Irene hit Vermont and brought with it significant inland flooding resulting in more than 500 miles of damaged roads and 200 damaged bridges. Rebuilding costs amounted to between $175 and $250 million (GCRP 2014). Hurricane Sandy resulted in roughly 150 deaths, damaged or destroyed 650,000 homes, and incurred between $60 and $80 billion in damages, second only to Hurricane Katrina as the most costly Atlantic Hurricane (GCRP citing Blake et al. 2013 and NOAA 2013). In New Jersey alone, repairing damaged power and gas lines is expected to cost roughly $1 billion, while fixing waste, water, and sewer systems is expected to cost $3 billion (GRCP 2014 citing Blake et al. 2013, NOAA 2013). Douglas et al. (2013) determined that damage in Boston from Hurricane Sandy could have been much worse — were Hurricane Sandy to have hit Boston 5.5 hours later, at high tide, up to 6 percent of Boston could have been flooded. Furthermore, a Sandy-type storm occurring with 2.5 feet of sea-level rise (within the projected 1- to 4-foot range by 2100), could cause over 30 percent of Boston to flood (Douglas et al. 2013).

Climate change could have other impacts on urban and rural areas. For example, urban and rural populations could increasingly demand air conditioning in the summer (*see* Section 5.5.2.1.7 for further discussion of the impact of heat events on human health), when higher electricity demand could shrink

the capacity reserve margins in the power system. Recreational sites such as parks and playgrounds are often located in low-elevation areas, and will be increasingly susceptible to storm surge flooding (*see* Section 5.5.2.1.5 for further discussion of the impact of storm surge on low-lying areas) (IPCC 2014b citing Rosenzweig and Solecki 2010).

5.5.3.1.7 Human Health

The projected increase in extreme heat events in the Northeast region could have significant implications for human health. Extreme heat events can lead to hospitalization and even premature death (GCRP 2014). One study projects that temperature increases would result in a 50 to 91 percent increase in heat-related deaths in Manhattan by the 2080s, relative to a 1980s baseline (GRCP 2014 citing Li et al. 2013). Moreover, in the rural areas of the Northeast region, air conditioning is not as prevalent as in urban areas. Areas of Northern New England, where heat waves have historically been rare, are projected to experience an increase in the number of hot days (>90 ^{o}F temperatures) from less than 5 to more than 15 per year by the 2050s under the higher (A2) warming scenario. Accordingly, these communities are especially vulnerable to high temperatures (GCRP 2014 citing Kunkel et al. 2013).

Increased temperatures can worsen air quality. Poor air quality causes respiratory ailments and can lead to premature mortality. These impacts, coupled with heat stress, will disproportionately affect vulnerable populations such as children, the elderly, low-income families, minorities, women,[62] less-educated citizens, rural residents, and people with pre-existing health conditions such as asthma (GCRP 2014). Increased ground-level ozone from warming is projected to result in a 7.3 percent increase in asthma-related emergency department visits in New York metropolitan area by the 2020s under the higher (A2) warming scenario, relative to a 1990 baseline of 650 visits (GCRP 2014 citing Sheffield et al. 2011).

Climate change could also increase both the frequency and potency of plant allergens. Changes in temperature and precipitation patterns could change the amount and timing of airborne allergens like pollen grains and fungal spores. Latitudes above 44°N have already experienced an increase in number of days in the ragweed pollen season of between 13 and 27 days per year since 1995 (GCRP 2014 citing Ziska et al. 2011). These changes could worsen allergy symptoms and even increase the prevalence of allergic diseases in the Northeast region (Frumhoff et al. 2007 citing Ziska et al. 2008). As indicated in experiments, increased concentrations of CO_2 can increase the allergenic potential of poison ivy (Frumhoff et al. 2007 citing Mohan et al. 2006) and pollen-producers such as ragweed and pine trees (Frumhoff et al. 2007 citing Wayne et al. 2002, Ziska et al. 2000).

The prevalence of vector-borne and waterborne illnesses, such as West Nile virus, could also increase under warming scenarios. Suitable habitat for the Asian Tiger Mosquito, a carrier of West Nile virus, is projected to increase from the current 5 percent of total land area in the northeastern United States to 16 percent in the next 20 years, and between 43 percent (under the lower [B2] emissions scenario) and 49 percent (under the higher [A2] emissions scenario) by 2100 (GCRP 2014 citing Rochlin et al. 2013). This would expose an additional 30 million northeastern residents to West Nile virus. Waterborne disease from untreated wastewater is sometimes released into local water bodies during extreme precipitation events. This can increase the risk of stomach illness—in Connecticut, for example, one study concluded that the risk of contracting a stomach illness while swimming increased after intense rainfall events (more than 1 inch of precipitation in a 24-hour period) (GCRP citing Kuntz

[62] According to Cutter (2003), in terms of health impacts, "women can have a more difficult time during recovery than men, often due to sector-specific employment, lower wages, and family care responsibilities." (pg. 246)

and Murray 2009), while in Milwaukee, another study found a correlation between diarrheal illness in children and sewage discharge from heavy rain events (GCRP citing Redman et al. 2007).

Not all human health impacts are projected to be negative. Along with an increase in heat-related deaths, a reduction in cold-related deaths is also projected (GCRP 2009). However, in temperate regions, including the Northeast, the reduction in cold-related deaths is not likely to entirely offset the increase in heat- related deaths (Frumhoff et al. 2007 citing Campbell-Lendrum and Woodruff 2006 and McMichael et al. 2006).

5.5.3.2 Southeast and the Caribbean

This section describes climate change impacts in the Southeast region of the United States—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and Puerto Rico—and the Caribbean. The Southeast region has 29,000 miles of coastline (NOAA 2010), including some of the areas in the continental United States that are most vulnerable to sea-level rise. Additionally, the region faces impacts from hurricanes and tropical storms, storm surge, erosion, saltwater intrusion, and heavy rain events. Overall, it has endured more billion-dollar weather disasters than any other U.S. region (GCRP 2014). Increases in average temperatures and changes in precipitation from climate change will affect human health; freshwater resources; food, fiber, and forest products; and terrestrial and freshwater ecosystems.

5.5.3.2.1 Observed and Projected Changes in Exposure

Over the past century, global sea level has risen about 8 inches (GCRP 2014). Land subsidence has resulted in slightly higher sea-level rise in the northern Gulf of Mexico and along the East Coast (Ingram et al. 2013 citing Mitchum 2011). Since the early 20th century, relative sea levels have risen by 0.08 to 0.12 inches (2.03 to 3.05 millimeters) per year along the Atlantic and Gulf Coasts (National Science and Technology Council 2008, EPA 2009). By reconstructing sea levels over the past 2,100 years, Kemp et al. (2011) found that sea level was relatively stable along the North Carolina coast from 100 BC until 950 AD, after which levels increased by 0.02 inches (0.6 millimeters) per year for 400 years, followed by a stable period until the 19th century. Sea level is projected to continue to rise with local projections varying based on rates of subsidence/uplift and changes in offshore currents (GCRP 2014 citing Parris et al. 2012 and Sallenger et al. 2012).

This is a region that experiences large spatial variability in annual temperatures from the warm Florida Keys to the cooler Appalachian mountain range. Although oscillating warm and cool periods have resulted in the Southeast experiencing no long-term average annual temperature trend since 1900 (i.e., over the entire record), there has been an increase by an average of 2°F since 1970 relative to 1901-1960, and the decade 2001 to 2010 was the warmest on record (GCRP 2014). This warming has been more notable during the summer months, particularly along the region's coastline (Kunkel et al. 2013). While the number of hot days above 95°F per year slightly decreased during the 20th century, there has been an upward trend since the 1970s (Kunkel et al. 2013). In addition, warm nights above 75°F have increased since the 1970s (GCRP 2014). Intense cold wave events have experienced no trend over the past century (Kunkel et al. 2013). The number of days with temperatures remaining below freezing has generally fallen across the Southeast since the 1931 to 1970 period, and this decrease is more pronounced in the northern part of the Southeast (Kunkel et al. 2013). Kaushal et al. (2010) documented rising water temperatures in streams and rivers throughout the United States, including the Potomac River. The Caribbean has experienced increasing hot days (with temperatures above 95°F) and nights (temperatures above 75°F) since the 1950s (GCRP 2014 citing PRCCC 2013).

Over the coming century, interior states are projected to warm by 1 to 2°F greater than coastal regions, with the regional average temperature projected to increase by 4 to 8°F, and temperatures in Puerto Rico are projected to rise between 2 to 5°F by the year 2100 (the range provided spans the 25th to 75th percentile range for higher (A2) and lower (B1) emissions scenarios) relative to 1901 to 1960 (GCRP 2014). By the 2041 to 2070 period, hot days (with maximum temperatures above 95°F) are projected to significantly increase by 27 days, under the higher (A2) emissions scenario, with southern Florida experiencing nearly 50 additional hot days per year relative to the 1971–2000 (Kunkel et al. 2013, GCRP 2014 citing Kunkel et al. 2013). Days below 32°F are projected to decrease in most of the region by between 5 and 20 days for the 2041 to 2070 period under the higher (A2) emissions scenario, with Kentucky, Tennessee, and Virginia experiencing nearly 25 fewer cold days per year relative to the 1980 to 2000 average (Kunkel et al. 2013).

Since 1900, there has not been a statistically significant trend in annual precipitation for the Southeast region as a whole, except along portions of the Gulf Coast which exhibited increases in annual precipitation (Kunkel et al. 2013). Despite the lack of an annual trend throughout the Southeast region, fall precipitation has increased and summer precipitation has decreased since 1900 (Kunkel et al. 2013). While many climate models project small precipitation changes relative to natural variations in the coming years, the southwest part of this region is expected to become drier while the northeast is expected to become wetter (Kunkel et al. 2013). In the Caribbean, the majority of models suggest decreases in precipitation (GCRP 2014 citing PRCCC 2013).

Across the Southeast, daily and 5-day rainfall intensities have increased (GCRP 2014 citing Ingram et al. 2013). The region has also experienced both increasingly arid and extremely wet summers (GCRP 2014 citing Kunkel et al. 2013). Under a moderately low (RCP4.5) emissions scenario, interannual variability of both drought and wet conditions is projected to increase over the course of the 21st century (Weubbles et al. 2013). Trends of increasing extreme precipitation witnessed both during the 20th century and the past decade are expected to continue throughout the coming century (GCRP 2014).

While there is some disagreement amongst scientists regarding the increasing or decreasing trend in the number of Atlantic hurricane and major hurricane landfalls over the past century (Kunkel et al. 2013 citing Blake et al. 2011, Landsea et al. 2010, Mann and Emmanuel 2006), some studies suggest that both climate change and natural variability has contributed to an increase in the number of Category 4 and 5 hurricanes in the Atlantic basin since the 1980s compared to the historical record (mid-1880s) (GCRP 2014). While the number of tropical storms is projected to decrease in number globally, their intensity is projected to increase, along with the prevalence of Category 4 and 5 storms (GCRP 2014 citing Knutson et al. 2010). Grinsted et al. (2013) estimate that a 1.8°F (1°C) increase in global temperature could result in a twofold to sevenfold increase in the frequency of Hurricane Katrina-magnitude events by 2100 under the lower (RCP4.5) emissions scenario.

In the Atlantic Ocean, sea surface temperatures are projected to increase, which could play a role in increasing the intensity of hurricanes. Rising sea levels, coupled with a likely increase in hurricane intensity, will contribute to greater storm-surge height, erosion, and flooding (GCRP 2014). Model results for a study of climate change impacts (i.e., sea-level rise) along the Gulf Coast conservatively estimated a range of 6.7- to 7.3-meters (22- to 24-foot) potential maximum surge for Category 3 hurricanes and 9 meters (30 feet) for Category 5 hurricanes. Observed storm surges during hurricanes Camille and Katrina reached 7.6 meters (25 feet) and 8.5 meters (28 feet), respectively (CCSP 2008a). Table 5.5.3-2 summarizes the projected trends for climate variables in the Southeast and the associated resources the trends will affect.

Table 5.5.3-2. Observed and Projected Trends in Environmental Variables for the Southeast

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	No 20th century temperature trend; recent warming observed since 1970 with average annual temperatures increasing 2°F along with an increase in hot days, warm nights, and a decline in cold events.	Average temperatures projected to increase by 4 to 8°F by 2100; temperatures in Puerto Rico expected to rise 2 to 5°F by 2100; greater warming for interior states relative to coastal states; increasing hot days; decreasing cold nights.	▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Freshwater resources ▪ Human health ▪ Human security
Precipitation	No statistically significant annual precipitation trend since 1900; statistically significant increase in fall precipitation and decrease in summer precipitation; increase in daily and 5-day rainfall intensities.	More frequent and intense heavy downpours; drier conditions in the south; wetter conditions in the north; more variable drought and wet conditions.	▪ Freshwater resources ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal and low-lying areas ▪ Food, fiber, and forest products
Sea level	Sea-level rise of 8 inches since 1900 (0.08 to 0.12 inches per year); similar to global trend, augmented by subsidence in different locations.	Sea-level rise of 1 to 4 feet above 1992 levels by 2100 with higher rise projected for some locations along the Southeast coastline (largely due to subsidence).	▪ Freshwater resources ▪ Ocean systems, coastal and low-lying areas ▪ Terrestrial and freshwater ecosystems ▪ Human security

Notes:
Sources: GCRP 2014, Kunkel et al. 2013.

5.5.3.2.2 Freshwater Resources

Despite uncertainties in projections of precipitation changes in the Southeast, evaporative losses are expected to increase with rising temperatures, leading to reduced water availability (GCRP 2014 citing PRCCC 2013, Ingram et al. 2013). Annual water availability in the Southeast is projected to decrease from roughly 17 inches in 2010 to about 14 inches by 2060 based on moderate (A1B) and low (B2) emissions scenarios (GCRP 2014 citing Sun et al. 2013). Projections vary within the region, but the western states in the Southeast (Louisiana, Arkansas, Alabama, northern Mississippi, Tennessee, and Kentucky) exhibit a statistically significant change in water availability, a decrease of between 5 and 6.4 percent by 2060 (GCRP 2014 citing Sun et al. 2013). Similarly, the Caribbean is expected to face severe water stress across all emissions scenarios (GCRP 2014 citing UNEP 2008).

Sea-level rise is contributing to a greater risk of saltwater intrusion into freshwater resources, such as aquaculture operations and aquifers (GCRP 2014 citing Twilley et al. 2001, SFWMD 2009, and Obeysekera et al. 2011). Saltwater migration into the surface waters of the southern Everglades would contaminate the Biscayne Aquifer at its headwaters, threatening Miami-Dade County's wellfields, which supply 2.5 million residents with potable water (Bloetscher et al. 2011). The city of Hallandale Beach, Florida, has already abandoned six of eight drinking water wells (GCRP 2014 citing Berry et al. 2011). Freshwater resources will also face competition from the agriculture (from rising food production to meet increased demand), energy (from increased air conditioning needs), and urban (to supply residents with drinking water) sectors (GCRP citing Ingram et al. 2013). Coastal communities might have to establish new freshwater wells farther inland in order to reduce their vulnerability to saltwater intrusion (GCRP 2014).

5.5.3.2.3 Terrestrial and Freshwater Ecosystems

Projected climate change will affect natural ecosystems and wildlife in the Southeast. Some tidal freshwater forests are retreating, while mangrove forests traditionally adapted to coastal ecosystems are moving landward (GCRP 2014). Since 1930, Louisiana has lost 1,800 square miles of coastal wetlands as a result of both natural and anthropogenic factors (GCRP 2014 citing State of Louisiana 2012 and Couvillion et al. 2011). The low-lying coast of Louisiana, which currently loses 6,200 hectares of wetlands per year, could be entirely underwater by 2100 with up to 4 feet of sea-level rise (Ingram et al. 2013 citing ASP 2011). Saltwater intrusion threatens estuarine and mangrove ecosystems, and has already been linked to the decline of bald cypress forests in Louisiana, cabbage palm forests in Florida, and the inland encroachment of salt-tolerant mangroves in Florida (EPA 2009, NRC 2008).

Increases in seasonal and annual temperatures, as well as sea-level rise, will also affect natural systems. For example:

- Reduction of wetlands from sea-level rise and other factors increases the likelihood of a loss of fishery habitat. Furthermore, warming sea temperatures may increase invasive species, changes in species growth rates, shifts in migratory patterns or dates, and alterations to spawning seasons (GCRP 2014 citing PRCCC 2013 and Osgood 2008).
- Changes in salinity and sea-level rise can outpace the ability of local vegetation to adapt. Similarly, wildfires, hurricanes, and other extreme weather events could produce similar outcomes, potentially pushing local ecosystems past a destabilizing point (GCRP 2014 citing IPCC 2007b, Burkett 2008, 2005).
- Although it is uncertain whether the Southeast will be wetter or drier under future climate change, closed-canopy forests could be threatened by drought stress, even under somewhat wetter conditions, due to higher average temperatures and increases in fire disturbance (CCSP 2008c).

5.5.3.2.4 Ocean Systems, Coastal, and Low-Lying Areas

Sea-level rise, increased hurricane intensity, storm surge, erosion, and saltwater intrusion are among the most serious climate change impacts facing the Southeast region. Miami is in the top 20 cities worldwide in terms of population exposed to future coastal flooding, and Miami, New Orleans, and Virginia Beach are all among the top 20 cities with the highest value of assets exposed to future coastal flooding impacts (Hanson et al. 2011, Weiss et al. 2011). In Miami, sea level rose 0.09 plus or minus 0.009 inches (2.39 plus or minus 0.22 millimeters) per year from 1913 to 1999, and barrier islands in the Tampa Bay region are already affected by significant beach erosion due to sea-level rise (Bloetscher et al. 2011). One analysis suggests that annual damage to assets on the Alabama, Mississippi, Louisiana, and Texas coastlines from hurricanes, subsidence, and sea-level rise could increase from the current $14 billion to between $18 and $23 billion, depending on the change in hurricane wind speed and sea-level rise (GCRP citing AWF, AEC, and Entergy 2010). The authors attribute roughly 50 percent of the increase in damages to climate change.

Transportation, utility, and energy sectors are projected to be affected by an increasing number of heavy rain and storm surge events. For example, Louisiana State Highway 1 is subsiding, putting the economically important oil and gas hub at risk of severe flooding (GCRP 2014 citing State of Louisiana 2012). The Department of Homeland security calculated that a 90-day severe flooding event at Louisiana State Highway 1 would cost $7.8 billion (GCRP 2014 citing DHS 2011). Further, 1 meter (3.3 feet) of sea-level rise combined with 7 meters (23 feet) of storm surge could inundate more than half of all highways, arterials, and rail lines along the U.S. Gulf Coast (IPCC 2013 citing CCSP 2008a). Sea-level

rise of 4 feet would permanently inundate 27 percent of roads, 9 percent of railways, and 72 percent of ports in the Gulf Coast (CCSP 2008a).

Water and energy utilities are expected to face pressure from saltwater intrusion into freshwater systems. Periods of drought can further reduce the availability of freshwater for municipal and agricultural consumption (GCRP 2014). Inland flooding could impair the ability of stormwater drainage systems to empty into the ocean (GCRP 2014 citing Bloetscher et al. 2011). Offshore oil and gas production infrastructure is expected to become increasingly vulnerable to storm surge as barrier islands that once protected them erode into the sea (GCRP 2014 citing Burkett 2011).

Many of the low-lying coastal areas exposed to sea-level rise, hurricanes, and storm surge are also at high risk of erosion. Significant erosion is already occurring along the east coast and in the coastal wetlands of Louisiana from a combination of factors, including climate change induced sea-level rise and land subsidence (National Science and Technology Council 2008 citing IPCC 2007b). Horizontal erosion rates on Mississippi shorelines have been between 8.5 and 10.2 feet per year since the 1970s[63]; in contrast, 90 percent of the Louisiana shoreline has eroded at 39 feet per year (EPA 2009 citing IPCC 2007b). The coastline of Puerto Rico is eroding at a rate of 3.3 feet per year due to current sea-level rise (GCRP 2014 citing PRCCC 2013). In Louisiana, barrier-island erosion is resulting in increased wave height along the coast (National Science and Technology Council 2008 citing IPCC 2007b).

Finally, climate change is expected to also affect coral reefs, which are already facing stress from overfishing, pollution from land-based runoff of nutrients and sediments, coastal developments, and disease. Reefs off the Florida Keys and in tropical waters in the United States face a dual threat from both warmer sea water and ocean acidification, which are expected to challenge their survival (GCRP 2014).

5.5.3.2.5 Food, Fiber, and Forest Products

Warmer temperatures, declines in soil moisture, and water scarcity will have impacts on agriculture in the Southeast region. Decreased freshwater availability, land loss, and saltwater intrusion could negatively affect agricultural production (GCRP 2014). Miami-Dade County and southern Louisiana, which have shallow groundwater tables, would lose 37,500 acres of cropland with a 27-inch rise in sea levels (within the 1- to 4-foot range projected by 2100) (GCRP 2014 citing Stanton and Ackerman 2007).

Dairy and livestock production are sensitive to increasing summer temperatures. With a 9°F temperature increase (slightly higher than the 4 to 8°F projected by end of century under the 75th percentile range across the lower [B2] and higher [A2] emissions scenarios), the Southeast region may experience a 10 percent decline in livestock yields largely driven by the warmer summers (GCRP 2014 citing Adams et al. 1999). Crop productivity would similarly be negatively affected by summer heat stress, as well as drought and an increase in nonnative plant species (GCRP 2014 citing Hellmann et al. 2008). While increasing CO_2 concentrations would increase the productivity of corn and wheat, increasing temperatures are projected to outweigh this effect due to summer heat stress (GCRP 2014 citing Hatfield et al. 2008). In Georgia, rising temperatures could lead to declines in corn and wheat yields of 15 and 20 percent, respectively, through 2020 (GCRP 2014 citing Alexandrov and Hoogenboom 2000). Fruit crops that require chilling periods could also be displaced as the southeastern climate warms (GCRP 2014 citing Hatfield et al. 2008).

[63] This statistic was developed for the Mississippi and Texas shoreline.

Forest-damaging wildfires are projected to increase as warming continues. Wildfires in the Southeast region, which experiences the greatest number of wildfires in the United States,[64] are expected to grow in intensity, number, and size under increasing temperatures and drought conditions (though up to a specific threshold, as increased fire frequency results in reduced fire intensity) (GCRP 2014 citing Gramley 2005 and Butry et al. 2001). Climate change is projected to further disturb forests by modifying insect and pathogen occurrences. Rising temperatures have affected certain populations of insects, such as the Hemlock woolly adelgid in the Southern Appalachians which has increased in recent years due to increasing temperatures; on the other hand, Southern Pine Beetle outbreaks have decreased (GCRP 2014 citing Friedenberg et al. 2007).

5.5.3.2.6 Human Health

Higher temperatures could affect human health by contributing to illness and even death in periods of extreme heat. Days over 95°F have increased in Atlanta, Miami, New Orleans, and Tampa, leading to an above-average number of deaths. Extreme heat events are projected to increase the formation of ground-level ozone in the 19 largest urban areas in the Southeast region relative to 2001 under the moderate (A1B) emissions scenario, which would lead to higher incidence of respiratory illness, asthma-related emergency room visits, and lost school days (GCRP 2014 citing Portier et al. 2010, Chang et al. 2010, and Tagaris et al. 2009). Forest fires also negatively affect human health by both causing direct injuries and lowering air quality (GCRP 2014 citing Butry et al. 2001, Albrecht et al. 2007, Ebi et al. 2008, and Delfino et al. 2009).

While it is uncertain how climate change will affect the spread of disease vectors like mosquitoes carrying malaria, yellow and dengue fever, increasing temperatures could result in expanded mosquito habitat (GCRP 2014 citing Filler et al. 2006, Mali et al. 2010, and Trout et al. 2010). Increased incidents of algal blooms due to warmer sea surface temperatures could result in higher rates of ciguatera fish poisoning (GCRP 2014 citing Tester et al. 2010 and Hales et al. 1999). Furthermore, warming sea surface temperatures could cause these algal blooms to move northward, as would bacteria present in shellfish, such as Vibrio (GCRP 2014 citing Litaker et al. 2010). Vibrio-related infections are now beginning earlier in the year and ending later in the year, compared to historical observations (GCRP 2014 citing Litaker et al. 2010).

5.5.3.2.7 Human Security

Storm surge and extreme weather threatens human wellbeing and livelihoods, especially in poor and disadvantaged communities located in low-lying areas. For example, as floodplains increase in size due to greater incidence of storm surge, insurance costs are expected to escalate, disproportionally affecting low-income communities (GCRP 2014 citing Leurig and Dlugolecki 2013). Insurance coverage could then become unaffordable or even unavailable, forcing residents to migrate to less vulnerable areas that could be unprepared to accept a population influx. For example, after Hurricane Katrina, 200,000 Gulf Coast residents moved to Houston, 42 percent of this population have indicated their desire to remain in Houston (GCRP 2014 citing Coker et al. 2006). In the Gulf Coast region, virtually all of the most socially vulnerable residents live in areas unlikely to see adaptation investment from storm surge due to low property values (GCRP 2014 citing Martinich et al. 2013).

Increased summer temperatures are expected to stress existing power plant capacity in the Southeast region, which has a greater capacity than any other U.S. region (GCRP 2014 citing EIA 2011). Increases in

[64] The data defines a larger Southeast area, including Texas and Oklahoma.

power demand, and inevitably energy prices, will disproportionately burden low-income households, the elderly, and native tribes (GCRP 2014 citing Ingram et al. 2013 and Coastal Louisiana Tribal Communities 2012).

5.5.3.3 Midwest

The Midwest region includes Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. Across the Midwest, where more than 61 million people populate the vast agricultural lands, northern forests, and major urban centers, which include Chicago, Cleveland, Detroit, Indianapolis, Milwaukee, St. Louis, Cincinnati, Kansas City, and Minneapolis- St. Paul (U.S. Department of Commerce 2013). The region is in the middle of the North American continent with four major urban areas situated on the shores of the Great Lakes, the largest lake system in the world and a defining feature of the region (Gronewold and Stowe 2014).

In the next few decades, climate change is expected to exacerbate existing climate-related risks to the Midwest region, including increase the frequency and intensity of extreme weather events, heat waves, and flooding events; change the composition of forests by driving the tree fauna northward; and catalyze threats to the Great Lakes, which include changes in range and distribution of aquatic species, increased persistence of invasive species and algal blooms, and declining beach health. These climate change impacts will have detrimental impacts on the region's agricultural productivity, human health, infrastructure, and ecosystems.

5.5.3.3.1 Observed and Projected Changes in Exposure

Overall temperatures in the Midwest have warmed in the past century by 1.5°F at a rate of 0.14°F per decade from 1901 to 2005. Recently, this warming rate has accelerated to 0.49°F per decade for 1979 to 2005 (Kunkel et al. 2013 citing Trenberth et al. 2007). From 1895 to 2012, average temperatures increased about 1.6°F. Average temperatures for the region are projected to continue to warm over the next few decades (2021 to 2050) by an additional 1.8°C (3.2°F) for a lower (B1) emission scenario to 4.3°C (7.74°F) for a higher (A2) emission scenario relative to the 1979 to 2000 period.[65] By the end of this century, average temperatures could increase between 2.7°C (4.9°F) to 4.7°C (8.5°F), for the lower (B1) and higher (A2) emission scenarios, respectively (Kunkel et al. 2013).

For ten Midwest cities, the number of hot humid days in the summer has increased over the period of 1940 to 2010, while the presence of cold dry air has decreased (Vanos et al.2014). In addition, major heat waves have become more frequent over the last 6 decades (GCRP 2014 citing Luber and McGeehin 2008). This trend is projected to continue as heat waves become longer, more frequent, and severe (EPA 2009, GCRP 2014 citing Luber and McGeehin 2008). Warming has also been notable during the winter, where the annual frost-free period has lengthened by about 2 to 3 weeks in recent decades (Kunkel et al.2013, EPA 2009, GCRP 2014).

Generally for the region, the annual precipitation has increased up to 20 percent in the last century with heavy precipitation events accounting for much of this increase (GCRP 2014 citing Pryor et al. 2009). From 1895 to 2011, observations suggest an increasing trend in annual precipitation of 0.31 inches per decade, with a statistically significant trend observed during summer (June, July, August) (Kunkel et al. 2013). Though there is large variability across the climate models, averaging the climate model projections suggest annual precipitation will continue to increase, more notably toward the north,

[65] These projections are based on the WCRP CMIP3 dataset.

with an intensification of the heaviest precipitation events throughout the region (Kunkel et al. 2013, GCRP 2014 citing Pryor et al. 2013 and Schoof et al. 2010). By the end of the century and under the higher (A2) emission scenario, the majority of the climate models suggest continued increases in precipitation during the winter and spring relative to 1971 to 2000 (GCRP 2014). For mid-century, regional climate models suggest an increase in springtime precipitation and a decrease in summertime precipitation relative to 1971 to 2000 under the higher (A2) emission scenario, particularly for the southern Midwest (GCRP 2014 citing Pryor et al. 2013). For the entire Midwest, a greater portion of precipitation is projected by both global and regional climate models to fall in more frequent and more intense extreme precipitation events, which now occur twice as frequently as a century ago (EPA 2009, GCRP 2014). Extreme precipitation events can have deleterious impacts on agricultural productivity, infrastructure, and ecosystems (Kunkel et al. 2013, GCRP 2014 citing Pryor 2013).

The Great Lakes have already started to experience increases in water temperatures and reductions in ice cover. Between 1968 and 2002, summer temperatures in Lake Huron increased by 5.2°F, Lake Ontario increased by 2.7°F, and Lake Superior increased by 4.5°F (GCRP 2014 citing Dobiesz and Lester 2009, Austin and Colman 2007). By 2050, the lakes are expected to increase in surface temperatures by as much as 7°F, and by 2100, as much as 12.1°F. The average annual ice coverage from 2003 to 2013 was lower than any other decade with recorded measurements, with an average of 43 percent coverage compared to the 52 percent average coverage from 1962 to 2013, although assumptions are based on surface area and vary substantially year to year (GCRP 2014 citing Bai and Wang 2012). Measurements in the Midwest indicate that, in addition to percent coverage, the duration of ice cover has also been decreasing in the past century (Kunkel et al. 2013).

Table 5.5.3-3 summarizes the observed and projected trends for climate variables in the Midwest and the associated resources the trends will affect.

Table 5.5.3-3. Observed and Projected Trends in Environmental Variables for the Midwest

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Over the past century, increasing annual average temperatures by about 0.9°C (1.5°F) per year with accelerated rate of warming in the most recent decades.	Increase in annual average temperatures, which is most notable during winter months; increase in humidity; increase in the severity, frequency, and duration of heat waves.	▪ Terrestrial and freshwater ecosystems ▪ Food, fiber, and forest products ▪ Human health
Precipitation	Over the past century, up to a 20% increase in annual precipitation with heavy precipitation events accounting for much of this increase.	Increase in precipitation, during winter and spring. Projected intensification and increased frequency of extreme precipitation events.	▪ Terrestrial and freshwater ecosystems ▪ Food, fiber, and forest products ▪ Urban areas ▪ Human health

Notes:
Sources: EPA 2009 and GCRP citing Kunkel et al. 2013, Pryor and Barthelmie 2013, Pan et al. 2009, and Pryor et al. 2009.

5.5.3.3.2 Terrestrial and Freshwater Ecosystems

The Midwest is rich with native flora and fauna diversity within the region's prairies, wetlands, lakes, streams, and forests (GCRP 2014 citing Bischof et al. 2013). Many of the native species and ecosystems, however, are vulnerable to climate change impacts. Traits that increase a species' vulnerability to climate change include a low range of physiological tolerance, dependence on isolated habitats,

dependence on relationships with other species, limitations in dispersal, low reproduction rates, and low genetic variability (GCRP 2014 citing Brook et al. 2008). When species are faced with potentially lethal impacts from climate change, they must move or adapt to survive; however, if fauna were to migrate to survive from rising temperatures, the flat terrain would require fauna to travel up to 90 miles north to reach climates 1.8°F cooler (EPA 2009, GCRP 2014 citing Jump et al. 2009).

With regard to flora, many forests will change in composition due to the rising temperatures. In both a lower (B1) emissions scenario and a high (A1FI) emissions scenario, habitats for native tree species, such as birches, aspens, and cypress will continue declining in northern forests as oak and pine forests may expand northward. These trends are projected more dramatically for the higher emissions scenario (GCRP 2014 citing Prasad et al. 2007). Results from high (A1FI) emissions scenarios indicate an overall pattern of reductions in flora diversity in higher temperatures and less productive soils (Duveneck 2014).

The combination of increasing temperature and precipitation, as well as decreases in ice cover, all threaten ecosystem health within the Great Lakes. Warmer temperatures have been observed to advance the pervasiveness of invasive species in the Great Lakes system, including sea lamprey, rainbow smelt, and other nonnative species (GCRP 2014 citing Bronte et al. 2003). Meanwhile, the habitat for cold water fish is expected to generally shrink, drastically altering the dispersal of fish species in the Great Lakes system, including lake trout and whitefish (EPA 2009, GCRP 2014 citing Austin and Colman 2007). Increasing temperatures will also increase the pervasiveness of algal blooms, which can cause "dead-zones" by depleting oxygen levels in the water that can "choke" fish and other aquatic plant species (EPA 2009). Lower oxygen levels in the lakes due to warmer water and increased algae can also increase persistence of mercury and other pollutants in the aquatic environment (EPA 2009).

5.5.3.3.3 Food, Fiber, and Forest Products

Anomalous weather events, higher temperatures, and changes in precipitation tend to have mixed impacts on agriculture in the Midwest, though generally, climate change impacts are detrimental to agricultural productivity (IPCC 2013 citing Hatfield et al. 2013). While higher temperatures, increased atmospheric CO_2 concentrations, and longer growing seasons from climate change have the potential to increase agricultural productivity, the increased productivity potential is offset by the freeze damage associated with the continued springtime cold air outbreaks projected throughout this century (GCRP 2014 citing Vavrus et al. 2006 and Gu et al. 2008). Heat waves during pollination and wetter springs also have the potential to reduce productivity of some crops (GCRP citing Hatfield et al. 2011 and Rosenzweig et al. 2002).

Climate change impacts vary by crop species. For instance, corn and soybeans, which make up about 85 percent of Midwest crop yields, will probably be affected very differently over the coming century (GCRP 2014 citing National Agricultural Statistics Service 2012). For corn, small long-term increases in temperatures may result in reduced reproductive development and smaller yields. For soybeans, yields might initially increase from CO_2 fertilization, however, the yields of corn and soybeans will decrease later in the century from temperature stresses (GCRP 2014 citing Parris et al. 2012, Yin et al. 2009, and Horton et al. 2011). While the days without precipitation are projected to increase, extreme precipitation events are projected to increase as well, leading to droughts and flooding that could both add further stress to crop yields. The livestock industry will also face productivity threats due to the higher prices of crops (from lower yields) and increased temperatures (EPA 2009).

5.5.3.3.4 Urban Areas

Much of the Midwest population lives in urban areas, where climate change may exacerbate urban heat island effects, water cycle variability, exposure to diseases, threats to aging infrastructure, and impediments to urban services such as transportation, energy, and potable water. Heat waves, which have increased in frequency and intensity in recent decades, are exacerbated in urban areas where dense populations and impermeable surfaces increase temperature variability (GCRP 2014 citing Luber and McGeehin 2008). Impervious surfaces in urban areas also create stormwater runoff, which, with increased precipitation, could increase the volume and frequency in discharges. Additional stormwater runoff will have greater potential to overwhelm sewage systems and carry contaminants into water systems, such as the Great Lakes, increasing nonpoint source pollution and eutrophication. Extreme precipitation events associated with climate change may also increase flooding, which can inundate many of the region's urban infrastructure (IPCC 2013 citing Villarini 2011). In addition to the threats transportation systems face from flooding, changes in water levels of the Great Lakes may affect the shipping industry in the region by limiting the size and weight of cargo ships permitted to transport goods (GCRP 2014 citing Sousounis et al. 2000). In recent years, the Great Lakes have experienced persistent reduction in water levels and recession in shorelines (Gronewald and Stow 2014).

Rising temperatures and increased heat waves are projected to increase demands for cooling to exceed 10 gigawatts by the middle of the century, which would require about $6 billion of investments in infrastructure. In addition, higher temperatures are projected to decrease efficiency in about 95 percent of electrical infrastructure (GCRP 2014 citing Gotham et al. 2013).

5.5.3.3.5 Human Health

Rising temperatures will probably have adverse impacts on human health in the region. The increase of frequency, severity, and length of heat waves, as well as the increased summer temperatures and humidity, may result in a greater risk of heat-related deaths (EPA 2009, GCRP 2014 citing Schoof 2013). One study found a greater frequency in heat waves that have lasted as much as 3 days longer in recent decades compared to historical records (Vanos et al. 2014). In another study, Chicago was projected to have an increase of 166 heat-related deaths per year in a lower (B1) emissions scenario and 2,217 heat-related deaths per year in a higher (A2) emissions scenario from 2081 to 2100, as compared to a 1987–2005 database on mortality (GCRP 2014 citing Peng et al. 2011).

In addition to driving climate change, human-induced emissions also deplete ambient air quality and have deleterious impacts on human health. More than 20 million Midwesterners are exposed to air quality that fails to meet national standards for air quality (EPA 2009, GCRP citing Pyror and Barthelmie 2013). Air pollutants, including particulate matter and ozone caused by automobile exhaust, may cause acute respiratory symptoms. Increased summer heat waves could raise ozone levels potentially increasing the number or severity of high pollution days in the Midwest (GCRP citing Gabrow et al. 2012). In addition, the increased growing season in response to rising temperatures may also increase the length of the pollen season and the risk of vector-borne diseases (GCRP 2014 citing Ziska et al.2011).

In urban areas, increased stormwater runoff could have detrimental impacts on human health through degrading the quality of freshwater resources. Many of the urban areas have combined sewage and storm drainage systems, and therefore, as extreme precipitation events increase, there is a greater likelihood of sewage overflow and degradation to water quality (EPA 2009, GCRP 2014 citing Patz et al. 2008). The Great Lakes have experienced such sewage overflows, affecting the drinking water of 40 million people and the swimming water of 500 beaches (GCRP 2014 citing Patz et al. 2008). Under a

high (A1FI) emissions scenario, one study projected the increase in storm events leading to a 120 percent increase in sewage overflows in Lake Michigan by 2100 (GCRP 2014 citing Patz et al. 2008).

5.5.3.4 Great Plains

This section discusses the impacts of climate change on the Great Plains region. This region covers the area including North and South Dakota, Kansas, Montana, Nebraska, Oklahoma, Texas, and Wyoming. The Great Plains are characterized by a highly diverse climate due to the region's large north–south extent and change of elevation (GCRP 2014). The region is vulnerable to climate-related impacts, including extreme temperatures, large variability in rainfall, and related extreme events (e.g., floods and droughts). These impacts have implications for the region's ecosystems, freshwater resources, and agriculture.

5.5.3.4.1 Observed and Projected Changes in Exposure

Since 1906, climate in the Great Plains has been generally warmer and wetter. Eight of the ten summers in the Great Plains between 2002 through 2011 were above the 1901 to 1960 average (Kunkel et al. 2013). States in the northern part of the region have experienced the greatest increase in long-term average temperatures, with North Dakota experiencing the fastest annual temperature increase over the last 130 years in the contiguous United States (GCRP 2014 citing Kunkel et al. 2013). In 2011, Dallas, Houston, Austin, Oklahoma City, Wichita, among other cities in the Great Plains region all set records for the number of days recording temperatures of 100°F or higher in those cities' recorded history (GCRP 2014). Under a lower (B2) emissions scenario, summer temperatures are expected to increase, with the number of days over 100°F projected to double in the north and quadruple in the south by mid-century (GCRP 2014).

The Great Plains are characterized by large discrepancies in precipitation patterns, with average annual precipitation greater than 50 inches in eastern Texas and Oklahoma while areas of Montana, Wyoming, and west Texas receiving less than 15 inches of rainfall a year (GCRP 2014). These precipitation patterns are projected to change, exhibiting seasonal and regional variations. Under a higher (A2) emissions scenario, winter and spring are anticipated to become wetter in the northern part of the region relative to a 1971 to 2000 baseline, while changes in the central areas are not expected to be greater than that already associated with natural variability (GCRP 2014 citing Kunkel et al. 2013). The number of days with heavy precipitation is expected to increase by mid-century, especially in the north, and large parts of Texas and Oklahoma are projected to see longer dry spells by mid-century (GCRP 2014 citing Kunkel et al. 2013).

Changes in these basic climate indicators point to the more frequent occurrence of extreme events such as heat waves, droughts, and floods. These trends and events will affect the region, including exacerbating its water stresses and affecting some key economic activities. Table 5.5.3-4 summarizes the projected trends for climate variables in the Great Plains and the associated resources the trends will affect.

Table 5.5.3-4. Observed and Projected Trends in Environmental Variables for the Great Plains

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Temperatures have been above the 1901 to 1906 average for the last 20 years, both annually and seasonally. Northern states in the region have experienced the greatest increases in their long-term average. temperatures.	Increases throughout the region in the number of hot days with the largest increases to occur in southwest Texas; increases of 20 to 30 days for the freeze-free season.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Human health
Precipitation	Annual precipitation was greater than average the last few years except for 2011; 20th century trends in precipitation are not statistically significant for any seasons.	Winter and spring will become wetter in the northern areas, but drier in the southern areas; summer months are projected to receive less rainfall.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems

Notes:
Source: Kunkel et al. 2013.

5.5.3.4.2 Freshwater Resources

Freshwater availability remains a large concern in the Great Plains in future projections. A study by the Bureau of Reclamation describes the regional differences in climate-related changes in U.S. streamflows. The study's analytical and modeling results for eight Bureau of Reclamation river basins indicate that the north-central region of the western United States, which includes much of the Great Plains region, is becoming wetter. The study's runoff projections indicate that cool-season runoff will increase over the 21st century for river basins in the north-central United States (Missouri) (U.S. Bureau of Reclamation 2011b). Further, recent studies suggest that increases in winter runoff rather than spring runoff could affect flood control procedures already in place. In the south, a trend toward more dry days and higher temperatures will increase evaporation and decrease water supplies, increasing the stress on the water resources and irrigation (GCRP 2014).

The U.S. Great Plains was identified as one of four global vulnerability hotspots for water availability from the 2030s and beyond, where anticipated withdrawals would exceed 40 percent of freshwater resources (IPCC 2014b citing Liu et al. 2013). A warming scenario of 2.5°C (4.5°F) or greater relative to 1990 is projected to decrease the recharge of the Ogallala aquifer region (the Great Plains' most important aquifer and primary water source) by 20 percent (EPA 2009). However, projections also indicate that in high-latitude and high-altitude areas (e.g., Columbia headwaters in Canada and Colorado headwaters in Wyoming), there is a chance that snowpack losses could be offset by cool-season precipitation increases (U.S. Bureau of Reclamation 2011b).

Warmer water temperatures could exacerbate the presence of invasive species, jeopardizing the health of existing wetlands. Warmer waters could also increase the probability of eutrophication in wetlands and water sources, thereby decreasing water quality levels (U.S. Bureau of Reclamation 2011b).

5.5.3.4.3 Terrestrial and Freshwater Ecosystems

The Great Plains region is home to unique ecosystems and wildlife, with over 10 percent of its land federally or state protected. Rising temperatures have caused many plants and animals to move from

habitats at increasingly faster rates, which over time may prove difficult to both the species in adapting to varied environments and to habitat communities undergoing the shifts in species (GCRP 2014 citing Chen et al. 2011, Parmesan 2007, and Samson et al. 2004)

The millions of wetlands in the North American Prairie Pothole region covering the Northern Great Plains are considered particularly vulnerable to a warmer and drier climate. The wetlands of this region are considered to be the most productive habitat for waterfowl in the world, and are estimated to support up to 80 percent of North America's ducks. Simulations suggest that in a drier climate, the most productive habitat for breeding waterfowl would shift from the center of the region in the Dakotas and southeastern Saskatchewan to the wetter eastern and northern fringes, areas that are less productive or where most wetlands have been drained, resulting in significant declines in productivity (Johnson et al. 2005).

Increased wildfires also threaten to disrupt or fundamentally alter the habitat of the Great Plains as a result of changing climate conditions. In Yellowstone National Park, the fire rotation (i.e., the number of years it would take to burn an area equal to the landscape area) for fires greater than 200 hectares is projected to decrease from 100 to 300 years to less than 30 years, possibly turning coniferous forests into woodlands and grasslands (GCRP 2014 citing Westerling et al. 2011). Both the frequency of large wildfires and changes in fire season length have increased substantially since 1985, and are closely linked with advances in timing of spring snowmelt (Bureau of Reclamation 2011b).

5.5.3.4.4 Food, Fiber, and Forest Products

Agricultural lands cover more than 70 percent of the Great Plains, representing much of the region's economic activities with a total market value of about $92 billion (GCRP citing USDA 2012). These activities are fundamentally sensitive to climate, including changes in temperature, rainfall, and extreme events. Over the last 70 years, winter wheat has been flowering 6 to 10 days earlier as a result of rising spring temperatures (GCRP 2014 citing Weiss et al. 2005). There is concern that crop yields will reduce in response to warming air temperatures.

Livestock also will be affected by changing climate in the region. As a result of rising temperatures, the estimated days to slaughter-weight for swine increased by an average of 3.7 days from the baseline of 61.2 days by 2040, according to a modeling exercise based on the Canadian Global Coupled Model (CGC) projections (USDA 2013 citing Frank et al 2001, USDA 2008). This would result in a $12.4 million in annual losses in the central United States for producers. Under the same model, time-to-slaughter weight for confined beef cattle in the central United States increased by 4.8 days above the 127-day baseline value, costing producers $43.9 million annually.

In the Great Plains region, the projected increase in drought frequency and severity will stress the region's water resources that supply water for the agriculture sector. In the southern plains, projected declines in precipitation and greater evaporation because of higher temperatures will increase stress on water resources for agriculture. Studies show the climate impacts of shifting from irrigated to dryland agriculture would reduce crop yield by roughly a factor of two (GCRP 2014 citing Colaizzi et al. 2009).

Rising temperatures can provide benefits such as a longer growing season. However, warmer winters can allow pests and invasive plants to survive the winter (GCRP 2014 citing Nardone et al. 2010).

Since 1994, winter mortality of bark beetle larvae in Wyoming has dropped from 80 to 10 percent due to mild winters (Epstein et al. 2006 citing Holsten et al. 2000). The USDA Forest Service reports that bark beetles have now affected more than 1.5 million acres in northern Colorado and southern Wyoming,

killing lodgepole pines and affecting watersheds, timber production, and wildlife habitats (USDA Forest Service 2008).

5.5.3.4.5 Human Health

As the climate warms throughout the Great Plains, elderly populations will become increasingly vulnerable to heat waves, particularly in warmer cities and communities with sub-standard housing (GCRP 2014 citing Longstreth 1999). Heat waves are projected to increase for this region, with the number of days over 100°F expected to double in the northern part of the region and quadruple in the southern part of the region by mid-century, even under a lower (B1) emissions scenario (GCRP 2014).

As temperatures warm, concentrations of some airborne pollutants and allergens are projected to increase (CCSP 2008c). From the southern to the northern region of the Great Plains, an increase in frost-free days has altered flowering patterns and increased the length of the pollen season for ragweed for up to 16 days between 1995 and 2009 (GCRP 2014 citing Ziska et al. 2011). Air pollution causes a number of respiratory ailments and can lead to premature death.

5.5.3.5 Southwest

The Southwest region is projected to face significant impacts from climate change. This region includes Arizona, California, Colorado, Nevada, New Mexico, and Utah. Limited water availability in this dry, warm region has resulted in more than a century of negotiations over water rights. Over the past 50 years, the timing of snowmelt and runoff has shifted earlier into the year, and 60 percent of this shift can be attributed to increased anthropogenic GHG emissions (GCRP 2014 citing Garfin et al. 2013). Temperatures in the Southwest are projected to increase by between 2 and 9.5°F by 2070 to 2099 relative to a 1971 to 1999 baseline, and across emissions scenarios. Clow (2010) found that from 1978 to 2007, a 1°C (1.8°F) to 1.5°C (2.7°F) increase in average November to January temperatures per decade contributed to Colorado snowmelt occurring 2 to 3 weeks earlier. Changes in snowmelt and runoff will likely have major impacts on the freshwater supply in the Southwest, the health of ecosystems, and human activities such as agriculture and managed lands.

5.5.3.5.1 Observed and Projected Changes in Exposure

The Southwest region is already experiencing warmer temperatures. Since 1950, temperatures have been hotter than in any period of comparable length in the past 600 years (GCRP 2014 citing Ababneh 2008, Bonfils et al. 2008, and Garfin et al. 2013). Temperatures between 2001 and 2010 were 2°F hotter than the 1901 to 2010 average; it was the hottest decade in the southwestern temperature record of 110 years (GCRP 2014 citing Garfin et al. 2013). Under the higher (A2) emissions scenario, southwestern average annual temperature is projected to increase by 2.5 to 5.5°F by 2041 to 2070 and 5.5 to 9.5°F by 2070 to 2099, all relative to a 1971 to 1999 baseline (GCRP 2014 citing Kunkel et al. 2013). Under the lower (B1) emissions scenario, southwestern average annual temperature is projected to increase by 2.5 to 4.5°F by 2041 to 2070 and 3.5 to 5.5°F by 2070 to 2099, all relative to a 1971 to 1999 baseline (GCRP 2014 citing Kunkel et al. 2013). Summer heat waves are projected to intensify and lengthen, while winter cold spells are expected to become less frequent (GCRP citing Gershunov et al. 2009, Kodra et al. 2011).

Some areas in the Southwest region have undergone precipitation increases and others have experienced decreases, and the amounts and types of precipitation are expected to change further into the future (GCRP 2014 citing Garfin et al. 2013). Since the 1960s, there has been less late-winter precipitation falling as snow along with earlier snowmelt (GCRP 2014 citing Hidalgo et al. 2009 and Pierce et al. 2008). The percentage of annual precipitation falling as rain rather than snow has increased

at 74 percent of the weather stations studied in the western mountains of the United States from 1949 through 2004 (EPA 2009). Precipitation that falls in the mountains as rain instead of snow reduces runoff from snowmelt during spring and summer months. From 2001 to 2010, streamflows in the Sacramento–San Joaquin river delta, the Colorado river, the Rio Grande river, and in the Great Basin have decreased by 5 to 37 percent below the 20th century average (GCRP 2014 citing Garfin et al. 2013). Under a higher (A2) emissions scenario, changes in winter and spring precipitation by the end of the century in the north, as well as summer and fall changes throughout the region, are smaller than natural variations (GCRP 2014 citing Kunkel et al. 2013). However, precipitation in the southern part of the region is nonetheless projected to decline by between 3 and 12 percent across B1 and A2 emissions scenarios, and exhibit no change or increase in the north (Kunkel et al. 2013). Winter and spring precipitation in the south, by contrast, is projected to decrease in the southern part of the region (GCRP 2014 citing Kunkel et al. 2013).

Historically, drought has stressed many areas of the Southwest region; additional decreases in precipitation are anticipated to exacerbate this existing stress as future droughts become more frequent and intense (GCRP 2014, EPA 2009). On average, during drought peak years, there has been a 63 percent decline in annual runoff in the Southwest region (Cayan et al. 2010). There is some evidence of long-term drying and increase in drought severity and duration in the Southwest (National Science and Technology Council 2008) that is probably a result of decadal-scale climate variability and long-term change (EPA 2009). Changes in the amount, timing, and type of precipitation have cascading impacts on the mountain snowpack and streamflows in the region.

A reduction in late-winter and spring snowpack followed by a reduction in runoff and soil moisture will further stress water supplies (GCRP 2014 citing Cayan et al. 2010, Cayan et al. 2008, and Christiansen and Lettenmaier 2006). Twenty-first century drought in the Southwest region is more extreme than any other drying conditions over the past 100 years, although not more severe than droughts of the past 2,000 years (GCRP 2014 citing Garfin et al. 2013). Simulations project more severe droughts during the second half of the century, with some lasting for 12 or more years (Cayan et al. 2010).

The timing of runoff is also anticipated to change over the 21st century. Median flows are projected to decline in most major southwestern rivers by the 2050s, and in all major southwestern rivers by the 2070s (relative to 1990 to 1999). Most notably, the Rio Grande at Elephant Butte Dam and San Joaquin River at Friant Dam are projected to decline in median flow by 16 and 11 percent, respectively (GCRP 2014 citing Garfin et al. 2013).

Sea-level rise is expected to affect the California coast. Over the last century the sea level on the California coast rose between 6.7 and 7.9 inches (GCRP 2014 citing NRC 2012). However, there is much variability in sea-level trends across the U.S. western coastline, depending on such factors as local land subsidence/uplift, changes in ocean circulation, and changes in ocean salinity. Continued sea-level rise will exacerbate the impacts of high tides, storm surges, and freshwater floods, resulting in property damage and erosion at higher levels than the Southwest region currently experiences (GCRP 2014).

The rate of sea-level rise in the Southwest region is projected to accelerate, increasing the vulnerability of coastal cities and tidal ecosystems to flooding and other hazards (GCRP 2014 citing NRC 2012, Bromirski et al. 2011, Romanovsky et al. 2011, Parris et al. 2012). Sea-level rise will increase coastal erosion and flooding during high tides and storm events. Under a 16-inch rise in sea level along the California coast, which could occur in the next 50 years, coastal highways, bridges, and airports will face increased risk of flooding (GCRP 2014 citing SFBCDC 2011). Los Angeles groundwater supply and estuaries would be at risk of saltwater contamination (GCRP 2014 citing Webb and Howard 2011), and approximately 180,000 acres of shoreline in the San Francisco Bay Area would be vulnerable to inundation. In addition, 90 to 95

percent of existing tidal marshes and flats would be affected, 20 percent of which would be vulnerable to permanent submersion or erosion (BCDC 2009 citing Heberger et al. 2009). Were sea level to increase by 3 feet, within the 1 to 4 foot range of projected global sea-level rise by the end of the century, the number of Californians at risk from a 1-in-100-year flood would increase from 260,000 to 420,000 assuming current population densities and existing exposure levels, where approximately 18 percent of this exposed population is considered highly vulnerable (GCRP 2014 citing Heberger et al. 2012, NRC 2012, Parris et al. 2012, Cooley et al. 2012). Table 5.5.3-5 summarizes the projected trends for climate variables in the Southwest and the associated resources the trends will affect.

Table 5.5.3-5. Observed and Projected Trends in Environmental Variables for the Southwest

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Temperatures between 2001 and 2010 almost 2°F hotter than 1901 to 2010 average; temperature trends are upward and statistically significant (at the 95% level) for each season, and the year as a whole; freeze-free season about 17 days longer than in early 20th century.	Average annual temperature increase between 2 and 9.5°F by 2070 to 2099 relative to 1971 to 1999; intensified summer heat waves; decreased wintertime cold air outbreaks; greatest warming in summer in central Utah; increases in number of days above 95°F; freeze-free season increases by 17 days in most of region; more pronounced decreases in late-winter and spring snowpack; earlier occurrence of snowmelt in the year.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Human health
Precipitation	Less late-winter precipitation falling as snow; earlier snowmelt; streamflows arriving earlier in the year;	Decreased annual precipitation of between 3 and 12% in the south across lower (B1) and higher (A2) emissions scenarios, no change or increased annual precipitation across lower (B1) and higher (A2) emissions scenarios in the north; frequency and intensity of extreme dry events will increase in the second half of the century.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems
Sea level	Over the past 100 years, sea level along the California coast has risen between 6.7 and 7.9 inches.	Sea levels will threaten both managed environments, such as highways and airports, and natural environments, such as estuaries and groundwater supplies.	▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal and low-lying areas

Notes:

Sources: GCRP 2014, Kunkel et al. 2013, Garfin et al. 2013.

5.5.3.5.2 Freshwater Resources

The major climate-related concern in the Southwest region is the availability of freshwater resources. The region has historically been faced with limited resources, large-scale agriculture, and rapid population growth. Freshwater is also critical to the health of natural ecosystems. A study by the Bureau of Reclamation (2011) found that basins in the Southwest are becoming drier. Reduced snowpack and irregular streamflow are two major driving factors in the availability of freshwater in the Southwest. Anthropogenic climate change has resulted in earlier peak flow of snowmelt runoff and

declines in water stored in snowpack in the western United States (IPCC 2014c). Climate change is projected to further reduce snowpack and streamflow (GCRP 2014).

There is a trend toward earlier spring snowmelt across much of the western United States. Across broad areas of the southwest (Colorado, Utah, northern Arizona, Wyoming, Idaho, Washington, and Southern California), snow-fed streamflows have arrived between 5 and 20 days earlier in the past decade relative to a 1950 to 2000 average (GCRP 2014 citing Garfin et al. 2013). Over the last century, stream discharge in the Rocky Mountain region has decreased by about 2 percent per decade (EPA 2009). By 2100, seven out of ten Rocky Mountain Creeks modeled by St. Jacques et al. (2013) demonstrate decreased streamflow under a higher (A2) emissions scenario. According to EPA (2009), loss of snowpack in the Sierra Nevada and Colorado River Basin could leave 41 percent of the water supply in southern California vulnerable by the 2020s.

Snow water equivalent (SWE), which describes the amount of water stored in a given volume of snow, provides a high correlation with early runoff and decreases in total runoff. Thus, projected changes in SWE inform future water availability in the Southwest region (GCRP 2014). Under a moderately high (A2) emissions scenario, Colorado, which contributes the greatest volume of snow to the Southwest, is projected to experience a reduction in SWE of 26 percent below the 1971 to 2000 average level by 2070 to 2099. SWE in California and Utah, the next two largest snow contributors to the Southwest, is projected to decrease by 57 and 44 percent below the 1971 to 2000 average by 2070 to 2099, respectively. While Arizona, Nevada, and New Mexico contribute far less snow to the regional total, declines in SWE are projected to experience greater percent change (88 percent, 69 percent, and 66 percent below the 1971 to 2000 average by 2070 to 2099, respectively) (GCRP 2014), which could present greater challenges for Arizona, Nevada, and New Mexico relative to the rest of the Southwest.

These additional strains on freshwater resources would have significant implications not only for freshwater resources but also for hydroelectric generation, agriculture, land use, and water management. A reduced water supply also will likely add conflict to the already contentious water rights issues in the region. Federal agencies have identified a number of areas, mostly in the West, where conflicts could arise over growing water shortages (DOI 2005, Brekke et al. 2009).

5.5.3.5.3 Terrestrial and Freshwater Ecosystems

Plant and animal species in the northern hemisphere are shifting ranges to the north and west and to higher elevations (Grimm et al. 2013). Many species could shift ranges so extensively by 2100 that they might alter biome composition across 5 to 20 percent of the United States (with a large number of these species residing in the southwestern United States) (Grimm et al. 2013). The following paragraphs provide examples of plant species, animal species, and ecosystems in the Southwest that have been observed or projected to be affected by changes in climate.

Regional tree dieback could convert temperate woodlands into temperate grasslands, which would decrease standing biomass, carbon content, net primary productivity, radiation-use efficiency, canopy closure, and leaf area (Grimm et al. 2013). The lower bound of the elevation range of half of the 28 mammal species in Yosemite National Park in California moved approximately 500 meters (1,640 feet) upward since they were first studied a century ago (Pimm 2009 citing Moritz et al. 2008).

Alpine meadow systems in the southern Rocky Mountains have shifted the timing of flowering from a unimodal peak, lasting most of the summer, to bimodal peaks. This has led to a reduction in the total number of mid-summer flowers. A shift in the timing and abundance of flowers might not coincide with traditional pollinators (Aldridge et al. 2011). If nectar is a primary food source for the pollinators, the

shift could result in a cycle of declining flowers and pollinators. Further, Kelly and Goulden (2008) documented dominant plant species in the Santa Rosa Mountains in Southern California increasing their average elevation by about 65 meters (213 feet) between an initial observation in 1977 and a follow-up examination in 2006 to 2007. The authors rule out air pollution or wildfires as determinant factors in their range shift, concluding that regional climate change is the stressor.

5.5.3.5.4 Food, Fiber, and Forest Products

Warmer temperatures and less precipitation will affect the diversity, type, and health of forests in the Southwest region. Bioclimatic modeling indicates a future decline in the diversity of tree species in the Southwest region. A recent study analyzing tree ring patterns concluded that the projected temperature increase, which is a significant driver of tree mortality events like the current southwestern drought (the worst drought since the late 1500s), will cause the average drought in the 2050s to be worse than the most severe droughts of the past 1000 years. Further, because many species dependent on southwestern forests have limited ability to adapt to climate change, temperature projections would result in species distributions quite different from what we observe today (Williams et al. 2013).

Temperature increases, drought, insect infestations, and accumulation of woody fuels and nonnative grasses contribute to the Southwest region's vulnerability to wildfire (GCRP 2014 citing Bonfils et al. 2008, Williams et al. 2010, Abatzoglou and Kolden 2011, and Moritz et al. 2012). From 1916 to 2004, climate change was more pivotal than all other factors in determining forest burn area (GCRP 2014 citing Littell et al. 2009, Marlon et al. 2012, Trouet et al. 2010, Swetnam 1993, Tayler and Scholl 2012, and Swetman et al. 2009). Between 1970 and 2003, warmer temperatures and arid conditions resulted in a 650 percent increase in burn area in the western United States mid-elevation conifer forests (GCRP 2014 citing Westerling et al. 2006). In addition to drought and higher temperatures, climate change-fueled increases in bark beetle and pine beetle outbreaks have been linked to declines in certain tree species. For example, wildfire coupled with bark beetle infestations have killed trees across 20 percent of Arizona and New Mexico forests from 1984 to 2008 (GCRP 2014 citing Williams et al. 2010).

As climate change intensifies, wildfires are predicted to increase. By the end of century, burn area is projected to double in the Southern Rockies (GCRP 2014 citing Litschert et al. 2012), to increase 74 percent in California as a whole, and potentially double in northern California under a moderately high (A2) emissions scenario (GCRP 2014 citing Westerling et al. 2011). Furthermore, increased wildfires will contribute to vegetation shifting upslope, increased prevalence of invasive plants, and conversions of forests to woodland or grassland (GCRP 2014 citing Abatzoglou and Kolden 2011, Allen and Breshears 1998). Forty percent of the Southwest region is projected to become vulnerable to vegetation shifts under a moderately high (A2) emissions scenario (GCRP 2014 citing Gonzalez et al. 2010).

Excluding Colorado, more than 92 percent of southwestern cropland is irrigated, and the agricultural sector is responsible for nearly 80 percent of all water withdrawals (GCRP 2014). It follows that farmland in the Southwest region—specifically in California, which produces roughly 95 percent of many high-value crops grown in the United States such as apricots, almonds, pistachios, and olives (GCRP 2014 citing Beach et al. 2010)—is projected to become increasingly vulnerable to the impacts of climate change. Longer frost-free seasons, less-frequent cold air outbreaks, and more frequent heat waves are expected to reduce corn, tree fruit, and grape yields, stress livestock production, and increase agricultural water consumption (GCRP 2014 citing Baldocchi and Wong 2008, Lobell et al. 2006, Purkey et al. 2008, and Battisti and Naylor 2009). Additionally, certain warm-season vegetable crops in California may not be viable in increasingly hot temperatures (GCRP 2014 citing Jackson et al. 2012, Jackson et al. 2011).

5.5.3.5.5 Human Health

The Southwest region's urban population rate of 92.7 percent (i.e., the percentage of the total population living within a city) is the highest in the United States, and contributes to increased vulnerability to climate impacts (GCRP 2014 citing U.S. Census Bureau 2012, California Department of Water Resources 2009, Ray et al. 2008, and Gleick 2010). Rising temperatures increase urban demand for vegetation to reduce the urban heat island effect, yet population growth will concurrently compete for water supplies. High temperatures also increase demand for air conditioning, which strains power systems already vulnerable to small disruptions. For example, in 2011 an 11-minute disturbance eventually led to 1.5 million people in San Diego without power for 12 hours (GCRP 2014 citing FERC and NAERC 2012). Powerless water treatment facilities were then unable to prevent the release of 1.9 million gallons of sewage onto nearby beaches (GCRP 2014 citing Medina 2011). Such strains on the power grid can lead to illness and death among at-risk populations, such as the elderly and minorities.

Heat waves result in large numbers of fatalities; a conservative estimate of deaths from a 2006 heat wave in California totaled 147 (Ostro et al. 2009). Increased frequency, duration, and intensity of heat waves in the southeast are projected to increase the number of fatalities from heat stress, which is the leading weather-related cause of death in the United States (GCRP 2014 citing NWS 2012, Gershunov et al. 2009, Gershunov et al. 2011, Sheridan et al. 2011, and Sheridan et al. 2012). Additionally, heat waves can exacerbate existing human health conditions, such as respiratory and heart disease, by increasing ozone formation (GCRP 2014 citing Ostro et al. 2011).

5.5.3.6 Northwest

This section discusses the impacts of climate change in the Northwest region—Idaho, Oregon, and Washington. This region has a varied topography and climate that includes shorelines, mountains, and desert. Key natural resources in the region are vulnerable to a range of climate hazards that will change as temperatures increase, precipitation patterns shift, and sea levels rise. As a result, the region may face water-related challenges, coastal vulnerabilities, impacts on forests, and changes in agricultural productivity. This section focuses on the climate impacts that are anticipated to affect the Northwest uniquely. General impacts such as the implications of extreme heat and air quality concerns on human health are addressed in the respective chapters.

5.5.3.6.1 Observed and Projected Changes in Exposure

The Northwest has observed increases in temperature, changes in precipitation patterns (that are less noticeable when compared to natural variation), and changes in the relative sea level. From 1895 to 2011, temperatures across the region have increased by 1.3°F with a notable increase in the number of recent heat waves (GCRP 2014 citing Kunkel et al. 2013). Though there has not been a statistically significant change in annual precipitation from 1895 to 2011, there has been an increase in the variability of annual precipitation since 1976 when compared to the previous 75 years (Kunkel et al. 2013). Sea level along much of the Northwest coastline has been falling due to "tectonic uplift" resulting in less observed sea-level rise than the global average (GCRP 2014); though some Puget Sound locations are experiencing subsidence and thus higher than average relative sea-level rise.

By end of century, average annual temperatures for the region is projected to increase by 3.3 to 9.7°F for lower (B1) to higher (A2) emissions scenarios compared to the 1970 to 1999 period, with summer experiencing the largest seasonal increase (GCRP 2014). Under the higher (A2) emissions scenario, the number of days with maximum temperatures exceeding 95°F are modeled to increase by as much as 18 days annually in southern Idaho for the 2041 to 2070 period compared to the 1990 to 2000 baseline (Kunkel et al. 2013). Projections for precipitation are less certain with large variations of wetter to drier

conditions projected across climate models and emission scenarios. By mid-century, annual precipitation projections suggest a range of plausible futures from an 11 percent decrease to a 12 percent increase relative to 1970 to 1999 (based on an ensemble of projections from 21 climate models and the low [B1] and moderate [A1B] emissions scenarios) (GCRP 2014 citing Mote et al. 2010). By the end of the century, the annual precipitation projections for the region ranges from a 10 percent decrease to an 18 percent increase relative to the 1970 to 1999 baseline (GCRP 2014 citing Mote et al. 2010).

The area-averaged snowpack on April 1 in the Cascade Mountains has decreased by approximately 20 percent since around 1950 (GCRP 2014 citing Mote 2006). This shift, driven by warmer temperatures, has resulted in an earlier spring snowmelt that occurred 0 to 30 days earlier than historical trends, depending on location (GCRP 2014 citing Stewart et al. 2005). The warming trend resulted in some areas experiencing a shift in the timing of snowmelt from summer to late winter/early spring. Since about 1950, snow-fed streamflow increased from 0 to 20 percent as a fraction of annual flow in the late winter/early spring (GCRP 2014 citing Stewart et al. 2005) and decreased in summer flows from 0 to 15 percent as a fraction of annual flow (GCRP 2014 citing Stewart et al. 2005). Snowmelt is projected to continue to shift 3 to 4 weeks earlier than the 20th century average with substantial reductions for summer flows by 2050 (GCRP 2014 citing Elsner et al. 2010). Models project basins with a significant snowmelt will experience reductions in summer flows by 2050, under all emissions scenarios considered in the NCA report (GCRP 2014 citing Elsner et al. 2010).

Warming is projected to increase river-related flood risk in most basins that have runoff peaks related to winter rainfall and spring snowmelt. Snow-dominant basins (i.e., where runoff is fed predominantly by snowmelt) are expected to remain largely unchanged with regard to river-related flooding (GCRP 2014 citing Mantua et al. 2010).

Models suggest that the number of days with more than 1 inch of precipitation in eastern Washington, Oregon, and northern Idaho will increase between the period of 2041 to 2070 and the 1980 to 2000 reference period. However, there is no statistically significant indication of a trend for the region (Kunkel et al. 2013). Rain-snow and rain-dominant basins may experience an increase in flood risk resulting from an increase in heavy downpours (GCRP 2014).

Table 5.5.3-6 summarizes the observed and projected trends for climate variables in the Northwest and the associated resources the trends will affect.

Table 5.5.3-6. Observed and Projected Trends in Environmental Variables for the Northwest

Environmental Variables	Observed Trend	Projected Trend	Affected Resource
Temperature	From 1895 to 2011, an increase in average temperatures of 1.3°F; generally low frequency of extreme cold periods since 1990 compared to the number of intense cold wave events since 1895.	2070 to 2090 projected average annual temperature increase 3.3 to 9.7°F for lower (B1) to higher (A2) emissions scenarios compared to the 1970 to 1999 period; seasonal temperature increase is projected to be largest during the summer.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems
Precipitation	Since 1976, annual precipitation has demonstrated high variability as compared to the previous 75 years. There has not been a statistically significant increase or decrease in precipitation during the 1895 to 2011 period. Changes to "extreme" events have not been statistically significant.	Large variation in annual precipitation changes across climate models and emission scenarios, with projections ranging from wetter to drier conditions.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas
Sea-Level Rise	Much of the Northwest coastline is rising due to "tectonic uplift" resulting in less observed sea-level rise than the global average. Some Puget Sound locations are experiencing subsidence and thus higher than average relative sea-level rise.	Global sea levels are projected to rise another 1 to 4 feet by 2100.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas

Notes:

Sources: GCRP 2014, Kunkel et al. 2013

5.5.3.6.2 Freshwater Resources

Climate change is projected to affect the timing and availability of freshwater resources in the Northwest. Although the annual amount of precipitation might remain relatively constant, population growth, increased temperatures, and the timing and type of precipitation are anticipated to stress the availability of sufficient freshwater. Water resources are essential across several competing uses, including irrigation, municipal and industrial use, hydropower production, and preservation of aquatic habitat. Further irrigation needs for crops could increase as earlier snowmelt leads to reduced spring soil moisture (GCRP 2014 citing Kunkel et al. 2013 and Bureau of Reclamation 2011). Reduced summer flows in basins with significant snowmelt will increase tension between the various uses. For example, demand for electric cooling, crops, and forests will increase simultaneously as the water resources become more scare in the summer months (GCRP 2014 citing Hamlet et al. 2010, Kunkel et al. 2013, and Bureau of Reclamation 2011).

5.5.3.6.3 Food, Fiber, and Forest Products

Higher temperatures and increased water deficits are expected to increase the number and extent of wildfires, promote the survival of invasive species, and shift the locations and diversity of forests (GCRP 2014). Water deficits increase tree stress, mortality, and vulnerability to insects, which can result in increased fuel for wildfires (GCRP 2014 citing Littell et al. 2012 and McKenzie et al. 2008). The number and extent of wildfires has increased in the forests of the western United States since the 1970s; the changes are associated with the timing of spring snowmelt (Westerling et al. 2006). An increase in wildfires could increase the threat of respiratory and cardiovascular illnesses in nearby populations (GCRP 2014 citing McKenney et al. 2011).

Increased disturbance and changes in forest extent and composition will result in changes to forest ecosystems upon which native species rely. Models suggest that subalpine and alpine ecosystems may convert to completely different vegetation types by the 2080s (GCRP 2014 citing Lenihan et al. 2008, Rogers et al. 2011 and Rehfeldt et al. 2012). These forest changes are expected to have an economic impact on the region, the greatest impact of which experience by the local timber and bioenergy markets (GCRP 2014 citing Capalbo et al. 2010).

Agriculture in the Northwest is projected to experience some short-term benefits but also face new obstacles with warmer temperatures, water deficits, changes in precipitation patterns, and shifts in the growing season (GCRP 2014). Agricultural commodities and food production systems contributed 14 percent of the region's 2009 gross domestic product (GCRP 2014 citing Brady and Taylor 2011). While a longer growing season and higher atmospheric CO_2 may benefit some crops in the short term (GCRP 2014 citing Stöckle et al. 2010 and Hatfield et al. 2011), warmer temperatures may negatively affect crops that are sensitive to heat stress, and water deficits may limit the water available for irrigation (GCRP 2014 citing Elsner et al. 2010). With regard to pests, higher average temperatures are associated with expanded geographic ranges, earlier emergence or arrival, and increased numbers of pests in some areas, which can negatively affect agricultural production (GCRP 2014 citing Parmesan 2006). Region-wide generalizations cannot be made since specific trends among pathogen and pest species react to a range of interactions (GCRP 2014 citing Juroszek and Tiedemann 2013).

5.5.3.6.4 Terrestrial and Freshwater Ecosystems

Changes in streamflow and water temperatures can affect stream ecology. In the Northwest, stream habitat is critical to the survival of several coldwater fish species, including salmon, steelhead, and trout. Rising stream temperatures increase disease and/or mortality in several salmon species, especially for spring/summer Chinook and sockeye (GCRP 2014 citing Crozier et al. 2008). Although the contribution of snowmelt to the streams may regulate temperature increases in the short term (GCRP 2014 citing Rieman and Isaak 2010), a decline in snowpack could eventually cause water temperatures to increase (GCRP 2014 citing Wenger et al. 2011). Compared to the period 1978 to 1997, suitable habitat for the four trout species in the interior region is projected to decline 47 percent on average by the 2080s, due to a combination of increases in temperatures, negative biotic interactions, and increases in winter flood frequency caused by warmer, rainier winters (Wenger et al. 2011).

Warmer lake temperatures also have been linked to earlier blooms of algae, which can disrupt the bottom of the food chain that can cascade up to larger, even keystone, species (GCRP 2014 citing Winder and Schindler 2004). Shifts in habitat and ecological conditions may lead to mismatches such as the availability of food sources (GCRP 2014 citing Winder and Schindler 2004).

5.5.3.6.5 Ocean Systems, Coastal, and Low-lying Areas

The Oregon and Washington coasts provide both natural resources and human uses that are important to the region for both economic and recreational reasons. Coastal and marine ecosystems are located along beaches, rocky shorelines, bluffs, and estuaries. Human uses include international ports and transportation systems that support rural and dense urban communities along the coast and throughout the region (GCRP 2014). Sea-level rise, erosion, inundation, and changes to the ocean chemistry pose a major threat to these critical costal resources.

The Northwest coastal waters are some of the most productive waters on the West Coast (GCRP 2014 citing Hickey and Banas 2008). Currently, the regional conditions and relative productivity are influenced by a variety of factors including sea surface temperatures, ocean acidity, and coastal upwelling, which may be influenced by climate change:

- Coastal inundation: As sea levels rise, coastal wetlands, tidal flats and beaches may experience more frequent inundation because more than 140,000 acres of these coastal lands lie less than 3.3 feet above high tide (GCRP 2014 citing Strauss et al. 2012). Species such as shorebirds and small fish that rely on these coastal habitats would be at greater risk from a decline in habitat availability and quality (GCRP 2014).
- Ocean acidification: Ocean waters are projected to become more acidic but acidity levels will vary by season and location (GCRP 2014 citing Feely et al. 2010, Feely et al. 2012, and Feely et al. 2008). Culturally and commercially important marine species, such as oysters and Pacific salmon are threatened either directly by changes in ocean chemistry or indirectly through changes in the food chain (GCRP 2014 citing Ries et al. 2009).
- Warmer ocean temperatures: Surface water temperatures are projected to increase 2.2°F during the 2030 to 2059 period, as compared to a 1970 to 1999 baseline, averaged across 20 climate models under the low (B1) and moderate (A1B) emission scenarios (GCRP 2014 citing Mote, Gavin, and Huyer 2010). Warmer water temperatures and ecological conditions may affect the location, type, and survival of marine species (GCRP 2014 citing Hollowed et al. 2001 and Tillmann and Siemann 2011). Warming temperatures have coincided with the arrival of subtropical and offshore marine species that are more common to the waters of Baja (GCRP 2014 citing Pearcy 2002). Regional estuaries, such as Puget Sound, may experience higher incidence of harmful algal blooms from warmer temperatures. The algal blooms are linked to paralytic shellfish poisoning (GCRP 2014 citing Moore et al. 2009) and could have negative economic impacts (GCRP 2014 citing Dyson and Huppert 2010).

In addition to the natural productivity of the coast, it supports many human uses for living, working, and recreation. Inundation from sea-level rise could affect essential industrial and community assets such as wastewater treatment plants (GCRP 2014 citing Solecki and Rosenzweig 2012 and King County Department of Natural Resources and Parks 2008); stormwater outfalls (GCRP 2014 citing Fleming and Rufo-Hill 2012 and Simpson 2011); ferry terminals (GCRP 2014 citing WSDOT 2011); and transportation networks, especially those in Puget Sound (GCRP 2014 citing MacArthur et al. 2012).

5.5.3.7 Alaska

This section focuses on the climate impacts anticipated to continue to affect Alaska. Alaska has marine, tundra, boreal forest, and rainforest ecosystems that are unique to this Arctic region and remain relatively intact. The region provides critical habitat for migratory birds, iconic caribou, fish, and marine mammals. The economy is driven by energy production, with mining, fishing, and tourism rounding out the top four industries (GCRP 2014 citing Leask et al. 2001). The region is home to 229 of the 566

federally recognized tribes in the United States (BIA 2014). Key climate change vulnerabilities in Alaska include declining sea ice, disappearing glaciers, thawing permafrost, changes in ocean temperature and chemistry, and impacts on the land and resources upon which native communities depend. These changes have significant impacts on freshwater resources; food, fiber, and forest products; terrestrial and freshwater ecosystems; ocean systems, coastal, and low-lying areas; urban areas; rural areas; and human security.

5.5.3.7.1 Observed and Projected Changes in Exposure

Alaska's large and diverse land area contributes to significant variations in climatic conditions. The climate is primarily influenced by latitude, altitude, proximity to the ocean, and the seasonal distribution of sea ice. Average annual temperatures can vary widely across the state, ranging from as low as -20°C (-4°F) in the northern latitudes to 11°C (52°F) in the southern coastal regions, as illustrated by the map in Figure 5.5.3-1 (Stewart et al. 2013). The temperature range between summer highs and winter lows is much greater in interior Alaska where the difference can be as much as 90°F. In contrast, southern areas are tempered by the maritime influence and have a much smaller inter-seasonal range on the order of 30 to 40°F (Stewart et al. 2013 citing Shulski and Wendler 2007).

Figure 5.5.3-1. Average Annual Temperature (°C) in Alaska

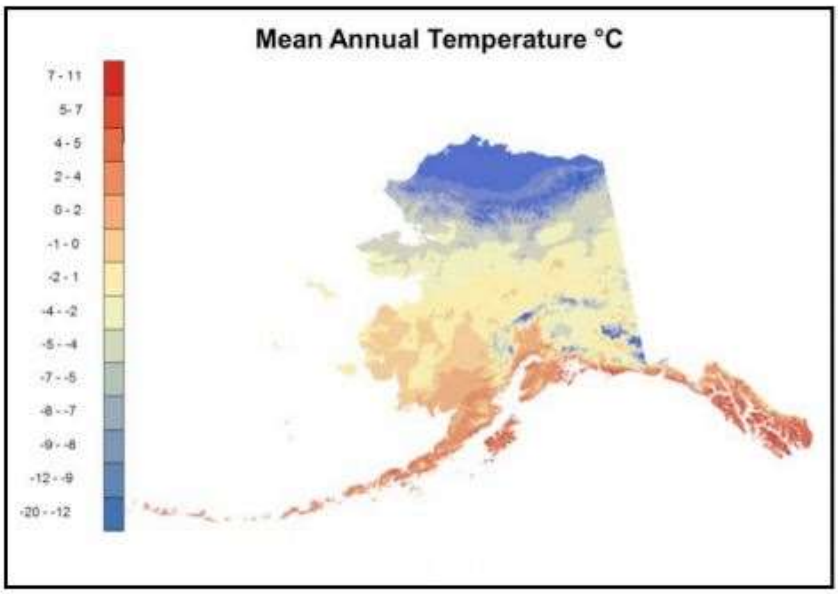


Figure 2. Mean annual temperature (°C) in Alaska for 2000-2009. Maps were produced by the Scenarios Network for Alaska Planning (SNAP) at the University of Alaska Fairbanks using data from the Climatic Research Unit (CRU) at the University of East Anglia, downscaled using the base climatology produced by the PRISM Climate Group at Oregon State University.

Source: Stewart et al. 2013.

Between 1949 and 2011, annual temperatures across Alaska increased an average of 3.0°F, with warming nearly twice as high in winter, increasing an average of 5.8°F, with substantial year-to-year variability (Stewart et al. 2013). Some communities, such as Big Delta in the Arctic interior, have experienced average winter temperature increases by as much as 9°F (Stewart et al. 2013). Alaska has experienced more days of extreme heat and fewer days of extreme cold with most anomalies representing a warming pattern since 1976 (GCRP 2014 citing CSSP 2008 and Stewart et al. 2013). By 2050, average annual temperatures in Alaska are projected to increase 2 to 4°F above a 1971 through 1999 baseline (GCRP 2014). This reflects a projected increase of 1.6 to 4.4°F under the low (B1) emissions scenario and

an increase of 1.8 to 5.5°F under the high (A2) emissions scenario by 2050 (Stewart et al. 2013). The higher end of the projected range covers a larger geographic region under the high (A2) emissions scenario, nearly entirely in higher latitudes, as compared to the low (B1) emissions scenario. By the end of the century, the difference in projections between the scenarios is more pronounced, where the upper range of temperature increase under the low (B1) emissions scenario increases to 7.5°F in the northern region. For the same time frame, under the high (A2) emissions scenario, the projected increase ranges from 5.5°F in the southern region to as much as 13.5°F in the most northern area of the state (Stewart et al. 2013). Projections vary for regions across the state with more rapid rates of warming are projected in the north, followed by the interior (GCRP 2014 citing Markon et al. 2012 and Stewart et al. 2013). Underlying long-term warming has moderated effects of Pacific Decadal Oscillation from shifting to its cooler phase in the early 2000s (GCRP 2014 citing Bieniek et al. 2014).

The average annual precipitation varies widely throughout the state. Figure 5.5.3-2 shows that precipitation may be limited to less than 6 inches per year in the Arctic and be as high as 200 inches annually in the coastal mountains in the southeastern panhandle (Stewart et al. 2013). From 1949 to 2005, the average statewide annual precipitation increased by approximately 10 percent, with notable regional and seasonal variation (Stewart et al. 2013 citing Shulski and Wendler 2007). All models projected an increase in precipitation during every season (Stewart et al. 2013). Annual precipitation is projected to increase 15 to 35 percent in Alaska by the end of the century, as compared to the 1971 to 1999 baseline. The greatest increases are projected to occur in the northwest region of the state, with the low (B1) emissions scenario projecting smaller increases (15 to 20 percent) in the region and the high (A2) emissions scenario projecting a greater increase (20 to 35 percent) in the northwest (Stewart et al. 2013).

Figure 5.5.3-2. Average Annual Precipitation (millimeters) in Alaska

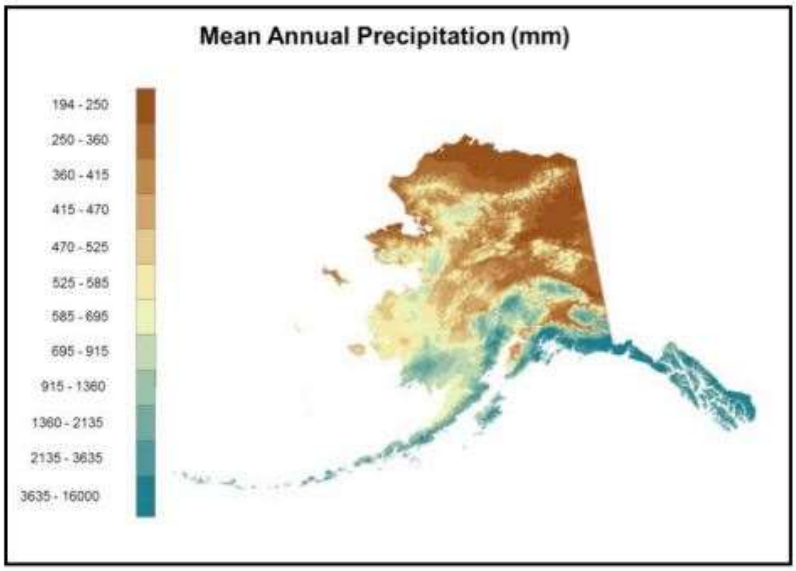


Figure 3. Mean annual precipitation (rain and melted snowfall, mm) in Alaska for 2000-2009. Maps were produced by the Scenarios Network for Alaska Planning (SNAP) at the University of Alaska Fairbanks using data from the Climatic Research Unit (CRU) at the University of East Anglia, downscaled using the base climatology produced by the PRISM Climate Group at Oregon State University.

Source: Stewart et al. 2013.

Table 5.5.3-7 summarizes the projected trends for climate variables in Alaska and the associated resources the trends will affect.

Two effects have led to the increases in average annual temperature: warmer temperatures and a self-reinforcing climate cycle, whereby warmer ocean temperatures melt more ice, creating more dark open water that absorbs even more heat, and results in the higher observed air temperature increases in the Arctic (GCRP 2014 citing Screen and Simmonds 2010). The extent and thickness of Arctic sea ice have declined substantially, and there is approximately half as much sea ice in late summer (September) as there had been when the satellite record began in 1979 (GCRP 2014 citing Maslowski et al. 2012 and Stroeve et al. 2012). The 2006 to 2013 period represents the seven Septembers with the lowest ice extent. By 2030, models that best match historical trends indicate that the northern waters will be nearly ice-free by late summer (GCRP 2014 citing Stroeve et al. 2007 and Stroeve 2012).

Table 5.5.3-7. Observed and Projected Trends in Environmental Variables for Alaska

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Over the past 60 years, average annual temperatures have increased 3°F with greater winter warming of approximately 6°F. More days of extreme heat and fewer extremely cold days with mostly warm anomalies since 1976.	By 2050, annual average temperatures are projected to increase another 2 to 4°F compared to a 1971 to 1999 baseline. The projected increase by 2100 is 4 to 8°F under a lower emissions scenario or as high as 6 to 12°F under a higher emissions scenario. Projections vary for regions of the state.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas ▪ Urban areas ▪ Rural areas ▪ Human security
Precipitation	Average statewide annual precipitation increased approximately 10% between 1949 and 2005.	Annual precipitation is projected to increase, especially in northwestern Alaska. Under the higher emissions scenario, precipitation increases are projected to be about 15 to 35% by the end of the century, compared to a 1979 to 1999 baseline.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems
Length of the Growing Season	The length of the growing season in interior Alaska has increased 45% over the past century.	Trend is projected to continue.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems

Notes:

Sources: GCRP 2014, Stewart et al. 2013.

Near the Alaskan Arctic coast, permafrost temperatures have warmed 4 to 5°F at a 65-foot depth since the 1970s (GCRP 2014 citing Osterkamp and Romanovsky 1999 and Romanovsky et al. 2012) and 6 to 8°F since the mid-1980s at a 3.3-foot depth (GCRP 2014 citing Romanovsky et al. 2008). The trend of warming and thawing is projected to continue (GCRP 2014 citing Avis et al. 2011 and Euskirchen et al. 2006), and some models project that, by the end of the century, large parts of Alaska will completely lose near-surface permafrost (GCRP 2014 citing Jafarov et al. 2012). By the end of the century, 57 percent of the state will lose permafrost within the top 2 meters (7 feet) (IPCC 2013b citing Marchenko et al. 2008).

5.5.3.7.2 Freshwater Resources

Some of the largest and most rapidly retreating glaciers in the world are located in Alaska (GCRP 2014 citing Berthier et al. 2010, Jacob et al. 2012, and Larsen et al. 2007). The primary cause for rapid ice loss on glaciers is rising temperatures (GCRP citing Arendt et al. 2002, Arendt et al. 2009, and Oerlemans 2005). Flat, low-lying, valley glaciers, such as those in Alaska, are currently demonstrating the most rapid mass loss (IPCC 2014). Glacial melt from Alaska and neighboring British Columbia, Canada, contributes approximately 40 to 70 gigatons of surplus freshwater to the oceans annually, about 20 to 30 percent of the amount that the Greenland ice sheet contributes (GCRP 2014 citing Jacob, Wahr et al. 2012, Kaser et al. 2006, Luthcke et al. 2008 and Pelto 2011). Glacial and ice-sheet melting is predicted to be one of the largest causes of global sea-level rise in the 21st century (GCRP 2014 citing Maier et al. 2005 and Radic and Hock 2011).

About half of the freshwater input in the Gulf of Alaska comes from glacial melt (GCRP 2014 citing Neal et al. 2010). Initially, the increased melt increases river discharge and hydropower potential, however, as the size of the glaciers decrease, the long-term water input may reduce hydropower resources (GCRP 2014 citing Cherry 2010).

5.5.3.7.3 Food, Fiber, and Forestry

There are nearly 80,000 Tribal members in Alaska (BIA 2014). Alaskan Native peoples are the most numerous residents in the rural northern regions of the state, where food and fuel prices are the highest and household income is limited (GCRP 2014 citing Goldsmith 2008). Warming ambient air temperatures, warmer water temperatures, thinning sea and river ice, altered spring run-off patterns, northward shifts in the habitat range of seals and fish, and rising sea levels all threaten critical food sources and the ability to maintain basic infrastructure in communities.

Alaskan Native peoples rely on hunting and fishing for sustenance, income, and their culture (GCRP 2014 citing Cochran et al. 2013, Huntington et al. 2005 and Kruse 1991). Thinning of sea and river ice makes hunting and harvesting more dangerous (GCRP 2014 citing Berner et al. 2005). The lack of sea ice for marine mammals has placed major food sources under stress (GCRP 2014 citing Galloway McLean et al. 2009) as seal and fish species move northward (GCRP 2014 citing Davis 2012), adding additional challenges to hunting. Thawing permafrost under warming conditions introduces new diseases to plants and animals, which can further threaten food resources (GCRP 2014 citing McLaughlin et al. 2005).

Glacial melt is an important source of organic carbon (GCRP 2014 citing Bhatia et al 2010 and Hood et al. 2009), phosphorus (GCRP 2014 citing Arendt et al. 2009), and iron (GCRP 2014 citing Schroth et al. 2011). Shifts in the inputs may impact near-shore fisheries (GCRP 2014 citing Hood et al. 2009 and Fellman et al. 2010). However, warming extends the growing season, improving the potential for gardening and agriculture (GCRP 2014 citing Markon et al. 2012 and Weller 2005).

Fishing is the third largest industry in Alaska (GCRP 2014 citing Leask et al. 2001). Ocean acidification, warming ocean temperatures, melting sea ice, and other environmental changes can shift the abundance and location of fish (GCRP 2014 citing Allison, Badjeck and Meinhold 2011, Cooley and Doney 2009, and Gaines et al. 2003). Recent changes have already resulted in near-surface fish species expanding their ranges northward (GCRP 2014 citing 104) and the invasion of nonnative species to occur more rapidly (GCRP 2014 citing Markon et al. 2012 and Ruiz et al. 2000).

Although warming waters may enable some species to move northward into areas that had previously been uninhabitable due to sea ice (GCRP 2014 citing Loeng et al. 2005), cold bottom-water temperatures along the Alaskan continental shelf could limit this migration (GCRP 2014 citing Sigler et

al. 2011). Additionally, warmer temperatures may affect fish species by reducing the abundance of species in their current geographic ranges (GCRP 2014 citing Mueter et al. 2011), threatening their health and survival (GCRP 2014 citing Farley et al. 2005), and increasing the frequency of early northward migration (GCRP 2014 citing Mundy and Evenson 2011). Change in the species mix, location, and timing of critical events introduce a new set of complications for fishery management and may cause the current fishing practices to be unsustainable (GCRP 2014 citing Mundy and Evenson 2011 and Hunt et al. 2011).

5.5.3.7.4 Terrestrial and Freshwater Ecosystems

Sea ice provides erosion control and protects coastal resources. Due to a decline in late-summer ice along the coast, storms have produced larger waves that cause more coastal erosion (GCRP 2014 citing Markon et al. 2012). Coastal bluffs, which had been previously "cemented" by ice-rich permafrost, are beginning to thaw and expose land that is susceptible to erosion (GCRP 2014 citing Overeem et al. 2011). There are several coastal communities where infrastructures and services have been affected by erosion, and a few communities have voted on community relocation or have already begun building infrastructure in a new location (Maldonado et al. 2013 and Bronen and Chapin 2013). *See* Section 5.5.2.9.

Permafrost thaw, greater rates of evaporation, and an increase in the accumulation of organic matter in soil due to a longer season for plant growth have decreased the area of lakes, on average, in the southern two-thirds of the state over the past 50 years (GCRP 2014 citing Klein et al. 2005, Roach et al. 2011, and Rover et al. 2012). However, the size of lakes in some locations is increasing as depressions at lake margins created by permafrost thaw are filled by melt water (GCRP 2014 citing Roach et al. 2011). These trends in permafrost thaw are projected to continue (GCRP 2014 citing Avis et al. 2011). Drying of lakes and wetlands could affect waterfowl nationally, because Alaska accounts for 81 percent of the National Wildlife Refuge system and provides critical breeding habitat for millions of migratory birds (GCRP 2014 citing CCSP 2008c).

5.5.3.7.5 Ocean Systems, Coastal, and Low-Lying Areas

Sea ice provides erosion control and protects coastal resources. Due to a decline in late-summer ice along the coast, storms have produced larger waves that cause more coastal erosion (GCRP 2014 citing Markon et al. 2012). Coastal bluffs, which had been previously "cemented" by ice-rich permafrost, are beginning to thaw and expose land that is susceptible to erosion (GCRP 2014 citing Overeem et al. 2011). There are several coastal communities where infrastructures and services have been affected by erosion, and a few communities have voted on community relocation or have already begun building infrastructure in a new location (Maldonado et al. 2013 and Bronen and Chapin 2013). *See* Section 5.5.2.9.

Globally, the absorption of human-produced CO_2 has caused ocean waters to become 30 percent more acidic. The North Pacific Ocean is particularly susceptible to this phenomenon (GCRP 2014 citing NOAA 2010), because cooler water absorbs CO_2 more readily than warmer water (GCRP 2014 citing NOAA 2010 and Steinacher et al. 2009) and melting sea ice causes the waters to have a lower salt content, which also allows for greater CO_2 absorption (GCRP 2014 citing Yamamoto-Kawai et al. 2009). Increased acidity could have far-reaching impacts on the marine food web. Higher acidity reduces the capacity of key plankton and shelled organisms to produce and maintain shells and hard parts. This reduces the amount of food available for larger fish species that contribute to the commercial and subsistence fisheries (GCRP 2014 citing Cooley and Doney 2009 and Sambrotto et al. 2008).

The rate of erosion along Alaska's northeastern coastline has doubled over the past 50 years as a result of melting sea ice, increasing summer sea surface temperatures, rising sea level, thawing coastal permafrost, and increases in storminess and waves (Jones et al. 2009). Most of Alaska's more than 200 native villages are experiencing coastal erosion and flooding, resulting in millions of dollars in property damage and threats to lives and property (GAO 2009). Since 2003, federal, state, and village officials have identified 31 villages facing imminent danger (USACE 2009), and 12 of these have decided to relocate. Health and sanitation concerns are also increased as thawing permafrost results in deteriorating water and sewage systems (GCRP 2014 citing Alessa et al. 2008 and Brubaker et al. 2011).

5.5.3.7.6 Urban Areas and Rural Areas

Alaska is unique in the United States in that approximately 80 percent of the land has permafrost (i.e., frozen ground that restricts water drainage) (GCRP 2014 citing Jorgenson et al. 2008). Permafrost thawing can cause damage to public infrastructure, such as disrupting water supplies and sewage systems (GCRP 2014 citing Alessa et al. 2008, Jones et al. 2009, and White et al. 2007), as well as roads, bridges, buildings, and airstrips (Karvetski et al. 2011 and Nelson et al. 2003). It is estimated that uneven sinking of the ground as a result of permafrost thaw will cost an additional $3.6 to $6.1 billion (10 to 20 percent) to maintain public infrastructure (GCRP 2014 citing Larsen et al. 2008). Additionally, permafrost vulnerability has decreased the period during which oil and gas exploration is permitted to about half the time permitted in the 1970s (GCRP 2014 citing Hinzman et al. 2005).

5.5.3.7.7 Human Security

As sea ice melts, the Arctic Ocean is becoming more accessible for marine traffic. Trans-Arctic shipping, oil and gas exploration, and tourism will have the capacity to expand with reduced ice extent (GCRP 2014 citing Smith and Stephenson 2013). Increased marine traffic could introduce or expand the risk for oil spills, maritime-related accidents, security challenges, international disputes, and traffic between the Pacific and Atlantic Oceans (GCRP 2014 citing Markon et al. 2012).

5.5.3.8 Islands (Hawaii and U.S. Affiliated Pacific Islands)[66]

This U.S. Pacific Islands include Hawaii, Federated States of Micronesia, Republic of the Marshall Islands, Republic of Palau, Territory of American Samoa, Territory of Guam, and Commonwealth of the Northern Mariana Islands. The region consists of more than 2,000 islands that span millions of square miles out into the ocean. These small islands are particularly vulnerable to climate change impacts, which will exacerbate current threats that islands are already facing: limitations of freshwater resources, frequency and intensity of tropical storms, ocean acidification, increasing ocean and ambient air temperatures, coastal erosion, sea-level rise, and threats to human security. These impacts have major implications for the islands' economies, communities, cultures, and aquatic and terrestrial ecosystems (GCRP 2014). Specifically, freshwater resources; ecosystems; agriculture and fisheries; and human security will be at risk.

5.5.3.8.1 Observed and Projected Changes in Exposure

Rising temperatures have been observed on U.S. tropical islands in recent decades and are projected to continue increasing (EPA 2009, GCRP 2014 citing Christensen et al. 2007 and IPCC 2007a). In a study using Atmosphere-Ocean General Circulation Models (AOGCM), projections were made over ocean

[66] Note that the Caribbean Islands, including Puerto Rico and the U.S. Virgin Islands, are covered with the Southeast region in this report.

surfaces, which were downscaled to predict temperatures over the land of islands since the AOGCM did not have a sufficiently fine resolution to capture the islands. In these projections, surface air temperatures increase 1.0 to 2.5°F by 2035 in Hawaii and the Central North Pacific (CNP) relative to 1971 to 2000 baseline (GCRP 2014 citing Christensen et al. 2007 and IPCC 2007a). In another study using a higher (A2) emissions scenario the Western North Pacific (WNP) is projected to have increasing surface air temperatures of 2.0 to 2.3°F by 2030 and 4.9 to 9.2°F by 2090 (GCRP 2014 citing Australian Bureau of Meteorology and CSIRO 2011). In the Central South Pacific (CSP), projected increases are to 1.1 to 1.3°F by 2030 and 2.5 to 4.9°F by 2090 under a higher (A2) emissions scenario, relative to 1971 to 2000 (GCRP 2014 citing Australian Bureau of Meteorology and CSIRO 2011). In Hawaii, high-elevation alpine ecosystems are already showing warmer temperatures that are projected to increase at a faster rate than lower elevation areas (GCRP 2014 citing Giambelluca et al. 2008 and Cao et al.2007). Sea surface temperatures are projected to increase as well. Under a lower (B1) emissions scenario, sea surface temperatures are projected to rise by 1.1°F by 2030, 1.8°F by 2055, and 2.5°F by 2090. Under a higher (A2) emissions scenario, sea surface temperatures could rise by 1.7°F by 2030, 2.3°F by 2055, and 4.7°F by 2090 compared to 1990 levels (GCRP 2014 citing Australian Bureau of Meteorology and CSIRO 2011).

While cyclical climate patterns such as El-Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) cause quite a bit of variability, thereby causing challenges in producing long-term precipitation trends, studies have identified regional precipitation trends within the U.S. Pacific Islands. For Hawaii and the eastern-most islands in the WNP, precipitation has been trending downward during the past century (Keener 2013). The eastern-most islands, such as the islands in the Micronesia region, have been observed to have 15 percent annual rainfall decline, yet the projected change in average annual precipitation over the period 2071 to 2099 under a higher emissions scenario that assumes continued increases in emissions (RCP 8.5) shows a projected increase in rainfall from 10 to 20 percent (GCRP 2014 citing NOAA NCDC/CICS-NC 2012). In the western-most islands, however, overall trends have been slightly upward in the WNP. American Samoa has no significant trends, but this is based on very limited available data (GCRP 2014 citing Ganachaud et al. 2011).

Precipitation projections for this region do not suggest a spatially uniform change. For Hawaii, precipitation may reduce by 5 to 10 percent during the wet season and increase by 5 percent during the dry season by the end of the century, based on projections from statistically downscaled climate data (GCRP 2014 citing Timm and Diaz 2009). In this study, the linear downscaling was applied to a projection of the IPCC AR4 climate scenario for Hawaiian rainfall, relative to the 1970 to 2000 time period (Timm and Diaz 2009). In Micronesia, precipitation is projected to increase by the end of the century, while in Hawaii, the projections show decreasing precipitation in the northwestern islands and no change to a slight increase on the main islands. Precipitation projections, however, are less certain than those for temperature and have lower confidence in the anticipated findings (Keener 2013).

With regard to sea-level rise, the global average has risen about 8 inches in the past century, with satellite observations indicating recent acceleration in the rate of se-level rise in the past 2 decades (GCRP 2014 citing Nerem et al. 2010). The IPCC AR5 also indicates that it is "*virtually certain*" that the global mean rates have accelerated in recent years and are projected to increase to the year 2100 (IPCC 2014b). Sea level of the Pacific is expected to rise at the global average rate with some regional variability due to changes in wind patterns, ocean circulation, storage in lakes and reservoirs, and melting glaciers (GCRP 2014 citing Stammer et al. 2013 and Seneviratne et al. 2012). For instance, regional sea level trends have demonstrated higher rates of rising in the western tropical Pacific than the global rates due to natural climate variability and changing wind patterns (GCRP 2014 citing Merrifield 2011). The U.S. Pacific Islands experience extreme sea level events when high tides are combined with other phenomena that affect water levels such as storms, ENSO, and other variations

(GCRP 2014 citing Merrifield 2011, Stammer et al. 2013, and Becker et al. 2012). Table 5.5.3-8 summarizes observed and projected trends in key environmental variables and affected resources.

Table 5.5.3-8. Observed and Projected Trends in Environmental Variables for the Islands

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Increasing temperatures in annual mean air and sea surface temperatures; faster rising rates in higher elevation areas in Hawaii.	Increasing temperatures in the ambient air in CNP, WNP, and CSP Islands with increasing rates in higher elevation areas in Hawaii; and increasing mean sea surface temperatures.	▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas
Precipitation	Decreasing precipitation in Hawaii and eastern WNP islands, increasing precipitation in the western WNP islands.	Increases in annual precipitation in Micronesia and main Hawaiian islands and reductions in northwestern Hawaiian islands by the end of the century.	▪ Freshwater resources ▪ Ocean systems, coastal, and low-lying areas ▪ Food, fiber, and forest products ▪ Human security
Sea level	Rising, with rates observed as continuing to accelerate.	Observed increasing rates of sea-level rise, particularly in the western tropical Pacific.	▪ Freshwater resources ▪ Ocean systems, coastal, and low-lying areas ▪ Food, fiber, and forest products ▪ Human security

Notes:

Sources: EPA 2009, Keener 2013, IPCC 2014, and GCRP 2014 citing Christensen et al. 2007, IPCC 2007a, Australian Bureau of Meteorology and CSIRO 2011, Timm and Diaz 2009, Nerem et al. 2010, and Merrifield 2011.

5.5.3.8.2 Freshwater Resources

The extent to which freshwater resources will be affected by climate change will vary for islands based on regional precipitation, ENSO events, storms, and climate variability, though generally, freshwater supplies are already constrained on islands and will continue to decline in availability (GCRP 2014 citing Oki 2004). In general, with temperature rising and precipitation decreasing on most islands, the availability of freshwater resources will be increasingly limited. Many small islands are already challenged with limited freshwater supply since highly volcanic and granitic islands, as well as islands with porous limestone, have limited storage capacity for precipitation (IPCC 2014b). Low-lying and smaller islands are also challenged with more limited availability of potable water sources, limited agricultural resources, geographic isolation, and increasing saltwater intrusion with sea-level rise and storms (GCRP 2014 citing Barnett and Adger 2003 and IPCC 2007b). Flooding from extreme events could also increase contamination risks to freshwater supplies from agriculture and sewage (EPA 2009). These trends on the U.S. Pacific Islands along with the geographic isolation and rising sea levels will stress islands' ecosystems, public health, agriculture, and communities (EPA 2009, GCRP 2014 citing Storlazzi et al. 2011).

5.5.3.8.3 Terrestrial and Freshwater Ecosystems

The U.S. Pacific Islands have many native flora and fauna species that are endemic to these small, biodiverse, and isolated terrestrial and freshwater ecosystems. Climate change impacts threaten the distribution, abundance, and overall existence of native island species with the combination of increasing temperatures, decreasing precipitation, and geographic isolation. Populations of terrestrial

species are expected to migrate to higher elevations in response to rising temperatures (IPCC 2014b, GCRP 2014 citing Benning 2002). Survival of native species will also depend on the level of fragmentation of ecosystems, disturbances from extreme weather, the availability of higher elevation habitats, the pervasiveness of invasive species, and the survival of keystone species[67] (GCRP 2014 citing Bradley 2010). Some Hawaiian tree species have already experienced stresses from drought and heat, causing dramatic reductions in endemic species' population in the past 20 years (GCRP 2014 citing Krushelnycky et al. 2013). Decreasing precipitation and increasing temperature will also threaten freshwater ecosystems and aquatic species due to the resulting reductions of freshwater habitats. Survival of many freshwater invertebrates and fish is also vulnerable to changes in streamflow and oceanic conditions from climate change because their reproduction cycle tends to depend on seasonal returns to inland and oceanic larval phases (GCRP 2014 citing Keith 2003).

5.5.3.8.4 Ocean Systems, Coastal, and Low-lying Areas

The future existence of coral reefs is seriously threatened by climate change impacts. Improved data and satellite observations provide ample evidence that sea-surface temperatures have already increased in the region and will continue to increase under B1 and A2 emissions scenarios (GCRP citing the Australian Bureau of Meteorology and CSIRO 2011). Ocean warming has contributed to the spread of coral disease outbreaks and coral bleaching (GCRP 2014 citing Bruno 2007). There are also projections under the A1B scenario that increasing levels of CO_2, from 380 ppm in 2005 to 450 ppm in 2030, and 500 ppm in 2050, will decrease the regional ocean pH from 3.5 in 2005 to 3.25 by 2030 and 3.0 by 2050. This decreasing ocean pH is reflective of ocean acidification, which has increased about 30 percent in recent decades and is projected to increase from 37 to 50 percent from present levels by 2100 (GCRP 2014 citing Feely et al. 2009).There is no long-term recovery for acidification and bleaching, and of all coral reefs, 90 percent are projected to suffer severe bleaching by 2055 under the IPCC AR5 new Representative Concentration Pathway experiments (Hooidonk et al. 2014).

At least three mass bleaching episodes have been observed in Hawaii in the past decade, while other incidences have been observed in Micronesia and American Samoa (GCRP 2014 citing Jokiel and Brown 2004 and Fenner et al. 2008). Ocean acidification will also lead to the degradation of calcium bi-carbonate, which is the building block of coral; increased mortality of Crutose coralline algae, which is also critical to the survival of coral; and increased fragility in surviving reefs (GCRP 2014 citing Kline et al. 2012 and Diaz-Pulido et al. 2012).

In a higher (A2) emissions scenario, continued loss of coral cover and coral reef habitat will result in extensive losses of reef species and fish (GCRP 2014 citing Pratchett 2011). In a lower (B1) emissions scenario, reefs are still projected to lose almost half of the associated species (GCRP 2014 citing Cesar and Beukering 2004). The ocean's uptake of CO_2 has also been found to change critical survival behaviors in fish, thus threatening to alter the patterns and characteristics of surviving reef fish (Munday et al. 2014). These threats have serious implications for the communities and species dependent on reef ecosystems and their role in the food web. Coral reefs also account for about $385 million in goods and services annually for Hawaii alone, demonstrating that damage to the reefs will directly affect the island communities' productivity and economy (GCRP 2014 citing Caser and Beukering 2004). Damage to the coral reefs will also result in extensive reductions in population size and diversity of reef fishes, which will have unquantifiable detrimental impacts on the local environments, tourism, and sustenance (GCRP 2014 citing Aeby et al. 2009).

[67] A species with a disproportionately large impact within the surrounding ecosystem due to its ability to maintain biodiversity by either controlling the population or by contributing as a major food source (Encyclopedia Britannica 2014).

In addition to providing habitat to a host of marine species, coral reefs also dissipate wave energy, thereby reducing coastal impacts of erosion and storm surges. With the "*high confidence*" that there will be more frequent and extreme oceanic storm events, depletion of the coral reefs surrounding the U.S. Pacific Islands will result in increased impacts from coastal erosion, storms, ENSO events, and sea-level rise (IPCC 2014b).

5.5.3.8.5 Food, Fiber, and Forest Products

Climate change is projected to affect fisheries and agriculture, which are critical to the livelihoods of island communities. In a higher (A2) emissions scenario, the catch of highly profitable fish are projected to decline; the bigeye catch tuna, for example, is projected to decline by 27 percent from 2000 levels by 2100 (GCRP 2014 citing Sussman et al. 2008). Agriculture productivity is also at risk from freshwater limitations, rising temperatures, and rising sea levels. In Micronesia, for instance, a staple crop, Taro, is highly vulnerable to saltwater intrusion. If the brackish water inundates the swamp where the Taro is grown, it will require about 2 to 3 years of precipitation to flush out the brackish water before the next harvest planting can begin (GCRP 2014).

Low-lying and smaller islands will be more vulnerable to decreases in agricultural productivity due to the greater risk of increasing groundwater salinity from intrusion and flooding (GCRP 2014 citing IPCC 2007b). Low-lying areas are also more vulnerable to major coastal alterations from sea-level rise. For example, based on extrapolations of mangrove resilience relative to sea-level rise in American Samoa, 10 to 20 percent of the regions' mangrove area will be lost over the next century due to sea-level rise, which would further reduce the nursery and feeding grounds for a host of species, shoreline protection, and water filtration (GCRP 2014 citing Gilman et al. 2008).

5.5.3.8.6 Human Security

Climate change could affect nearly every aspect of life for the residents of the U.S. Pacific Islands. While island size is in jeopardy from sea-level rise and increasing coastal erosion, inland infrastructure is also threatened by increased wave heights, flooding, and extreme events. Airports and road networks are particularly vulnerable to climate change impacts, as they are typically located in the low-lying portions of islands (GCRP 2014 citing IPCC 2007b). Damage to these transportation systems would be extremely detrimental to island communities, as the geographic isolation of islands tends to lead to great dependency on importation for food, fuel, and other goods (GCRP 2014 citing Lewis 2012). Sea-level rise, extreme storm events, and flooding are also expected to overwhelm island sewage systems, destroy coastal artifacts and structures, impede cultural practices, and threaten the existence of traditional foods (GCRP 2014 citing Henry and Jeffrey 2008, and Codiga and Wager 2011). Depletion of the coral reefs, terrestrial environments, freshwater resources, infrastructure, and local economies could ultimately threaten the existence of U.S. Pacific Island communities and could lead inhabitants of the islands to consider emigration. This could lead to a slew of new challenges faced by the migrants and the receiving countries including employment, resources, placement, and governing of possible masses of island migrants (GCRP 2014).

5.5.3.9 Indigenous Peoples

This section focuses on the climate impacts anticipated to affect the indigenous peoples. Key climate change vulnerabilities for indigenous peoples include traditional knowledge, traditional food sources, water quality and quantity, sea ice, permafrost, and forced relocation. Indigenous peoples are likely to be disproportionally affected by climate change impacts since their diets, culture, and infrastructure are closely tied to local resources. Furthermore, many tribes lack the financial resources to adequately adapt and respond to climate change—as exemplified by a 28.4 percent poverty rate of native peoples,

compared to 15.3 percent poverty rate nationally (GCRP 2014 citing Freeman and Fox 2005, Macartney, Bishaw, and Fontenot 2013).

5.5.3.9.1 Observed and Projected Changes in Exposure

Many Native American reservations are located in the Northwest, Southwest, Great Plains, and Alaska (GCRP 2014 citing Norris, Vines, and Hoeffel 2012). Due to the geographic diversity, the climate change impacts and trends are discussed in the respective regional chapters. The climate stressors of most relevancy for this population group are increased temperatures, changes in precipitation patterns, and sea-level rise. These environmental variables have observed and projected impacts on traditional knowledge; food, fiber, and forest products; freshwater resources, rural areas, human health, and human security. In this section, traditional knowledge is treated as a unique resource to indigenous peoples.

5.5.3.9.2 Impacts of Climate Change on Traditional Knowledge

Working Group II of the Intergovernmental Panel on Climate Change Fourth Assessment Report has identified traditional knowledge as an important component to understanding climatic changes and developing adaptation strategies (GCRP 2014 citing IPCC 2007b). Those living off of the land have been longstanding climate change witnesses, and are at times best equipped to report shifts in local ecosystems. A tribe located on the northern Great Plains, for example, has tracked climatic changes through yearly pictographs of buffalo hides (GCRP 2014 citing Nickels et al. 2005). In some cases, scientists have recognized the importance of traditional knowledge in documenting climate change, and have started to work with tribal leaders. On the Navajo Reservation, scientists and the Navajo elders worked together to observe meteorological and hydrological changes (GCRP 2014 citing Redsteer et al. 2011). The EPA Region 10 Tribal Leaders Summit 2010 Action Plan states that the federal agencies in collaboration with tribes in Region 10 "will sponsor a workshop to explore the connections between indigenous knowledge, citizen science, and western science" (Vinyeta and Lynn 2013 citing EPA 2010).

According to GCRP 2014, "many indigenous resource managers believe their cultures already possess sufficient knowledge to respond to climate change" (GCRP 2014 citing First Stewards 2012, Merideth et al. 1998). Traditional knowledge is passed down through cultural elements, such as song, dance, and storytelling. However, as traditional ways of life are becoming increasingly threatened by climate change, the tribal leaders' knowledge is declining with each new generation (GCRP 2014).

5.5.3.9.3 Food, Fiber, and Forestry

Climate change is threatening indigenous peoples' traditional food sources, as agricultural seasons are shortening, migration patterns are shifting, and arctic hunting grounds are melting. Shifts from traditional diets have led to health problems, food insecurity, reliance on costly nontraditional foods, and loss of culture (GCRP 2014 citing Cochran et al. 2013, Lynn et al. 2013, U.S. Commission on Civil Rights 2003).

Some climate change impacts on traditional food sources, such as species loss and shifts in species range, have already been observed (GCRP 2014 citing Cochran et al. 2013, Coastal Louisiana Tribal Communities 2013, Rose 2010, Swinomish Indian Tribal Community 2010). For example, warmer winters in Maine are lengthening the tick season, which causes harm to the moose population (GCRP 2014 citing Daigle and Putnam 2009). Additionally, wild rice has been increasingly difficult to grow within historical ranges in the Great Lakes region due to changes in temperature and water levels (GCRP 2014). Range shifts in forest foods, such as berries, have also been observed by the Wabanaki tribe in the northeast (GCRP 2014). Similarly, according to GCRP 2014, shifts in growing areas have caused some

medicinal foods to become sparse (GCRP 2014 citing Lynn et al. 2013, Riley et al. 2012). The Yakama Nation, comprised of 14 tribes, has already begun to create water management plans, anticipating the impacts of limited water resources on their traditional, salmon-heavy diets (Montag et al. 2014).

Furthermore, climate change may affect cultural traditions tied to food. For example, certain Alaskan Natives have cultural ties with animals, such as seals and caribou; these species will experience changes to their habitat as a result of climate change (EPA 2013 citing GCRP 2014).

5.5.3.9.4 Freshwater Resources

Climate change impacts—such as droughts and changes in precipitation—are threating indigenous peoples' access to sufficient quantities of quality water. This is made worse by poor government policies and regulations. For example, extractive industries near native lands are decreasing water supplies and contaminating water (e.g., an oil spill upstream from a reservation in North Dakota in 2013) (GCRP 2014).

Additionally, many indigenous cultures lack the financial resources necessary to maintain basic water infrastructure (GCRP 2014 citing Ferguson et al. 2011). As a result, several reservations have water infrastructure that is in need of repair or lacking entirely. For example, 30 percent of the Navajo Nation do not have access to municipal water systems and fetch water from local water resources (GCRP 2014 citing Navajo Nation Department of Water Resources 2011, Redsteer et al. 2011).

Other tribes along the coasts are facing ocean acidification and shoreline erosion. The Shinnecock Indian Nation in Long Island, for example, has experienced poor shellfish survival rates and loss of trees along the shoreline. The Shinnecock Indian Nation, similar to other coastal tribes, is also particularly vulnerable to flooding and storm surges (Shinnecock Indian Nation 2013).

5.5.3.9.5 Rural Communities

Climate change is causing increasing temperatures and melting the sea ice. Information from NASA Earth Observatory 2012 revealed that from 1979 to 2000, the average area of sea ice in the Arctic Ocean was 2.59 million square miles. By the end of the summer 2012, the sea ice area had been reduced to 1.32 million square miles (GCRP 2014 citing NASA Earth Observatory 2012). The sea ice is expected to continue to melt as temperatures rise (GCRP 2014 citing Pungowiyi 2009, Hinzman et al. 2005, Laidler et al. 2009, Pungowiyi 2002).

Declining sea ice directly affects those native Alaskan populations who live on the ice. The impacts include loss of culture as sacred areas become unsafe or unusable; food insecurity as animals migrate beyond hunting ranges; increased risk for hunting, fishing, or herding as sea ice thins; increased risk from severe storms as protection from coastal sea ice is eroded; and forced relocation of entire tribes as areas become inhabitable (GCRP 2014 citing Cochran et al. 2013, Brubaker et al. 2011, Pungowiyi 2002, Parkinson 2010, NASA Earth Observatory 2012).

5.5.3.9.6 Human Health

Climate change is causing increasing temperatures, thawing permafrost—otherwise known as *permanently frozen soil*. When permafrost melts, the land above it sinks and changes shape. Sinking land damages buildings, roads, water pipes, and leads to land erosion. Permafrost thaw can also lead to increased flooding and health issues (GCRP 2014). For example, many Alaskan Native communities depend on permafrost to store frozen foods. Modern electric alternatives are expensive (GCRP 2014). Decline in proper refrigeration is affecting health as food becomes contaminated, or tribes are

otherwise more dependent on less healthy, store-bought foods (GCRP 2014 citing Cochran et al. 2013, Parkinson and Evengard 2009, Brubaker et al. 2009).

Land erosion caused by permafrost thaw results in "loss of clean water for drinking and hygiene, saltwater intrusion, and sewage contamination" that could cause health issues, such as "respiratory and gastrointestinal infections, pneumonia, and skin infections" (GCRP 2014 citing Cochran et al. 2013, Parkinson 2010, McClintock 2009, Parkinson and Evangard 2009).

5.5.3.9.7 Human Security

Climate change impacts, such as sea-level rise, increase in severe storms, drought, and shifts in diseases, are forcing many native communities to consider relocation. Over 30 Alaskan villages are in need of relocation, or are already in the process of moving (GCRP 2014 citing Cochran et al. 2013, Bender et al. 2011). Tribal communities in Louisiana are facing inhabitable lands due to rising sea levels, salt water intrusion, and pollution from nearby extractive industries (GCRP 2014 citing Maldonado et al. 2013, Coastal Louisiana Tribal Communities 2012). "The Quileute tribe in northern Washington is responding to increased winter storms and flooding connected with increased precipitation by relocating some of their village homes and buildings to higher ground within 772 acres of Olympic National Park that has been transferred to them; the Hoh tribe is also looking at similar options for relocation" (GCRP 2014 citing Papiez 2009, Walker 2012, Quileute Newsletter 2011). For native Pacific Island communities, rising sea levels are forcing them to consider relocation (GCRP 2014 citing Souka and Tanimoto 2012, IPCC 2007a).

"Currently, the [United States] lacks an institutional framework to relocate entire communities. National, state, local, and tribal government agencies lack the legal authority and technical, organizational, and financial capacity to implement relocation processes for communities forcibly displaced by climate change" (GCRP 2014 citing Maldonado et al. 2013, Whyte 2013). For the Newtok—a village in Alaska—climate change has affected their infrastructure and basic necessities (GCRP 2014 citing Maldonado et al. 2013, Cochran et al. 2013). Their progress toward relocation has been limited by federal statutes and regulations. Additional barriers toward relocation for any Alaskan Native villages, such as the Newtok, include an absence of legal authority and governance structure (GCRP 2014 citing Maldonado et al. 2013, Bronen 2011, Alaska Department of Commerce and Community Economic Development 2012).

For those tribes who have already relocated, the displacement is causing loss of identity and culture, increased health risks, and is further exacerbating poverty (GCRP 2014).

5.6 Non-Climate Cumulative Impacts of Carbon Dioxide

This section describes the non-climate cumulative impacts of CO_2, including ocean acidification (5.6.2.1) and effects on plant and soil microorganism growth and diversity (5.6.2.2).

5.6.1 Affected Environment

In addition to its role as a GHG in the atmosphere, CO_2 is exchanged between the atmosphere and water, plants, and soil. CO_2 readily dissolves in water, combining with water molecules to form carbonic acid. The amount of CO_2 dissolved in the upper ocean is related to its concentration in the air. About 30 percent of each year's emissions (Canadell et al. 2007) dissolves in the ocean by this process; as the atmospheric concentration continues to increase, the amount of CO_2 dissolved will increase. Although this process moderates the increase in the atmospheric concentration of CO_2, it also increases the

acidity of the ocean. Increasing CO_2 concentrations in the atmosphere and surface waters will have a global effect on the oceans; by 2100, the average ocean pH could drop by 0.3 to 0.4 unit compared to ocean pH today (Caldeira and Wickett 2005, Feely et al. 2009).

Terrestrial plants remove CO_2 from the atmosphere through photosynthesis, using the carbon for plant growth. This uptake of carbon by plants can result in an atmospheric CO_2 concentration approximately 3 percent lower in the growing season than in the non-growing season (Perry 1994 citing Schneider and Londer 1984). Increased levels of atmospheric CO_2 essentially act as a fertilizer, positively influencing normal annual terrestrial plant growth. Over recent decades, terrestrial carbon uptake has been equivalent to approximately 30 percent of each year's CO_2 emissions (Canadell et al. 2007); this process is about equal to CO_2 dissolution in ocean waters in moderating the effect of increasing CO_2 emissions on the atmospheric CO_2 concentration.

In addition, the concentration of CO_2 in the atmosphere affects soil microorganisms. Recent research has underscored the importance of feedbacks between the aboveground and belowground components of terrestrial ecosystems in controlling ecosystem processes. For example, plants provide most of the organic carbon required for belowground decomposition. Plants also provide the resources for microorganisms associated with roots (Wardle et al. 2004). The "decomposer subsystem in turn breaks down dead plant material, and indirectly regulates plant growth and community composition by determining the supply of available root nutrients" (Wardle et al. 2004).

Specific plant species, depending on the quantity and quality of resources provided to belowground components, might have greater impacts on soil biota and the processes regulated by those biota than other plants. Variations in the quality of forest litter produced by coexisting species of trees, for example, "explain the patchy distribution of soil organisms and process rates that result from 'single tree' effects" (Wardle et al. 2004). The composition of plant communities has a consistent and substantial impact on the composition of root-associated microbes. However, the effects of plant community composition on decomposer systems are apparently context-dependent. In one study, manipulating the composition of plant communities in five sites in Europe produced distinct effects on decomposer microbes, while root-related soil microbes experienced no clear effect (Wardle et al. 2004).

Terrestrial communities contain as much carbon as the atmosphere. Forest ecosystems, including forest soils, play a key role in storing carbon. The amount of carbon stored in soils of temperate and boreal forests is about four times greater than the carbon stored by vegetation, and is 33 percent higher than total carbon storage in tropical forests (Heath et al. 2005). Forest soils are the longest-lived carbon pools in terrestrial ecosystems (King et al. 2004). Several experiments involving increases of atmospheric CO_2 resulted in increasing carbon mass in trees but a reduction of carbon sequestration in soils. This observation is attributable to increased soil microorganism respiration (Heath et al. 2005, Black 2008); respiration is associated with "root herbivory, predation, consumption of root exudates, and the decomposition of root and leaf litter" (King et al. 2004). Under climate change, the reduction of soil carbon via increased soil respiration could be counterbalanced by an increase in litter on the forest floor due to increased productivity. However, one recent study suggests that while increasing carbon could increase root production, it could decrease the quality of forest litter (Pritchard 2011).

5.6.2 Environmental Consequences

Sections 5.6.2.1 and 5.6.2.2 provide a qualitative analysis of non-climate cumulative impacts of CO_2. As with the climatic effects of CO_2, the changes in non-climate impacts associated with the action alternatives are difficult to assess quantitatively because the incremental changes in atmospheric CO_2 associated with the action alternatives translate to very small changes in ocean acidification and CO_2

fertilization. Nonetheless, it is clear that a reduction in the rate of increase in atmospheric CO_2, which all the action alternatives would provide to some extent, would reduce non-climate impacts of CO_2, such as the ocean acidification effect and the CO_2 fertilization effect described in Sections 5.6.2.1 and 5.6.2.2.

5.6.2.1 Ocean Acidification

Ocean acidification occurs when CO_2 dissolves in seawater, initiating a series of chemical reactions that increases the concentration of hydrogen ions and, thus, makes seawater more acidic (IPCC 2007a, Doney et al. 2009a, 2000b, Feely et al. 2009). An important consequence of this change in ocean chemistry is that the excess hydrogen ions bind with carbonate ions, making the carbonate ions less available to marine organisms for forming the calcium carbonate minerals (mostly aragonite or calcite) that make up their shells, skeletons, and other hard parts. Once formed, aragonite and calcite will re-dissolve in the surrounding seawater unless the water contains a sufficiently high carbonate ion concentration (*see* reviews by Doney 2009a, Doney et al. 2009b, 2009c, EPA 2009, Fabry et al. 2008, IPCC 2007a, Guinotte and Fabry 2008, The Royal Society 2005, NRC 2010, and SCBD 2009).

The findings on ocean acidification presented in this section are drawn primarily from recently released reports including the *IPCC GC1 AR5* (IPCC 2013a, IPCC 2013b) and the U.S. Global Climate Research Program (USGCRP) *National Climate Assessment (NCA) Report* (GCRP 2014).

These key findings include information on the oceans' role in absorbing CO_2 (and heat), the resulting increase in ocean acidity, and the impacts of ocean acidification on marine life.

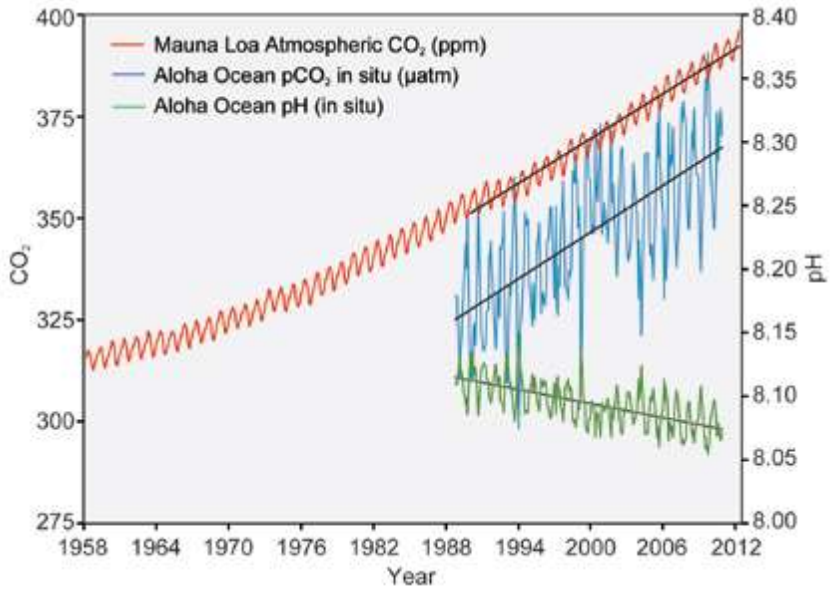
5.6.2.1.1 Increases in Ocean Acidity Resulting From CO_2 Emissions

The SPM reports that atmospheric concentrations of CO_2, CH_4, and NO_x have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40 percent since preindustrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. Both the SPM and NCA report that the ocean has absorbed about 30 percent of the emitted anthropogenic CO_2, causing ocean acidification (*see* Figure 5.6.2-1). The SPM also reports that the pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*), corresponding to a 26 percent increase in hydrogen ion concentration,[68] and that further uptake of carbon by the ocean will increase ocean acidification. Under all four (RCPs) scenarios, ocean uptake of anthropogenic CO_2 would continue through to 2100, with higher uptake for higher concentration pathways (*very high confidence*).[69]

[68] Ocean acidification is quantified by decreases in pH; pH is a measure of acidity using a logarithmic scale: a pH decrease of 1 unit corresponds to a 10-fold increase in hydrogen ion concentration, or acidity.

[69] Earth System Models project a global increase in ocean acidification for all RCP scenarios. The corresponding decrease in surface ocean pH by the end of 21st century is in the range18 of 0.06 to 0.07 for RCP2.6, 0.14 to 0.15 for RCP4.5, 0.20 to 0.21 for RCP6.0, and 0.30 to 0.32 for RCP8.5.

Figure 5.6.2-1. As Oceans Absorb CO_2 They Become More Acidic[a,b]



[a] Source: NCA 2014 modified from Feely et al. 2009.

[b] The correlation between rising levels of CO_2 in the atmosphere (red) with rising CO_2 levels (blue) and falling pH in the ocean (green). As CO_2 accumulates in the ocean, the water becomes more acidic (the pH declines).

The GCRP reports that projections indicate that in higher emissions pathways, such as SRES A2 or RCP 8.5, pH could be reduced from the current level of 8.1 to as low as 7.8 by the end of the century (GCRP 2014 citing Orr et al. 2005). Such large changes in ocean pH have probably not been experienced on the planet for the past 100 million years, and it is unclear whether and how quickly ocean life could adapt to such rapid acidification (GCRP 2014 citing Hönisch et al. 2012).

The SPM briefly notes that geoengineering methods proposed to deliberately alter the climate system to counter climate change (e.g., solar radiation management) may have the potential to substantially offset a global temperature rise (as well as modify the global water cycle), but they would not reduce ocean acidification (*see* also GCRP 2014).

5.6.2.1.2 Impacts of Ocean Acidification on Marine Life

The NCA reports that ocean waters are becoming warmer and more acidic, broadly affecting ocean circulation, chemistry, ecosystems, and marine life. More acidic waters inhibit the formation of shells, skeletons, and coral reefs. Warmer waters harm coral reefs and alter the distribution, abundance, and productivity of many marine species. The rising temperature and changing chemistry of ocean water combine with other stresses, such as overfishing and coastal and marine pollution, to alter marine -based food production and harm fishing communities (GCRP 2014). There are already a number of corals proposed for listing or reclassification under the Endangered Species Act.[70]

The NCA also reports that ocean acidification is expected to affect ocean species to varying degrees. For example, some photosynthetic algae and seagrass species could benefit from higher CO_2 conditions in the ocean, as they require CO_2 to live, as do plants on land. On the other hand, studies have shown that

[70] *See* http://www.nmfs.noaa.gov/pr/species/invertebrates/corals.htm.

a more acidic environment has dramatic negative effects on some calcifying species, including pteropods, oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. When shelled species are at risk, the entire food web could also be at risk (GCRP 2014). As a likely result, there is a rapid growth in peer-reviewed publications describing how ocean acidification will impact ecosystems (GCRP 2014 citing Cooley et al. 2009 and Doney et al. 2009), but to date, evidence is largely based on studies of calcification rather than growth, reproduction, and survival of organisms. For these latter effects, available evidence is from laboratory studies in low pH conditions, rather than in situ observations (GCRP 2014 citing Kroeker et al. 2013). Although studies are underway to expand understanding of ocean acidification on all aspects of organismal physiology, much remains to be learned (GCRP 2014).

That said, confidence is *very high* that CO_2 emissions to the atmosphere are causing ocean acidification, and *high* that this will alter marine ecosystems. The nature of those alterations is unclear, however, and predictions of most specific ecosystem changes have *low confidence* at present, but with *medium confidence* for coral reefs (GCRP 2014).

5.6.2.2 Plant Growth and Soil Microorganisms

Plants and soil microorganisms, both key players in terrestrial carbon storage, are predicted to have complex responses to climate-induced changes (GCRP 2014 citing Melillo et al. 2011, IPCC 2013). For example, several studies have shown that increased CO_2 concentrations increase the growth rates of some plant species under conditions of sufficient water and nutrient availability (GCRP 2014, Rosenthal and Tomeo 2013). However, while increased growth rates do potentially increase carbon sequestration, they do not necessarily lead to increased plant production or yield (GCRP 2014). That is, while changes in temperature, CO_2 concentrations, and solar radiation could benefit plant growth rates, such rates will not necessarily translate to increased yield of grain, forage, fruit, or fiber (GCRP 2014). Reductions in solar radiation over the last 60 years (due to increased clouds and humidity) (GCRP 2014 citing Qian et al. 2007) are projected to continue (GCRP 2014 citing Pan et al. 2004) which can reduce high temperature and elevated CO_2 accelerated plant growth (GCRP 2014). Overall projections for crop production systems indicate that climate change effects over the next 25 years will be mixed (Walthall et al. 2012) although most predictions for climate change effects on crop yields by 2050 are negative (Nelson et al. 2014).

Similarly, the effects of climate change on soil microbial communities and their corresponding impacts on terrestrial carbon pools are complex and not well understood (Wieder et al. 2014). The soil microbial community and structure is comprised of numerous species (including bacteria and fungi) whose survival and growth rates are affected by temperature, moisture, nitrogen, phosphorus, soil type, extreme weather events, land management practices and the local plant community structure (GCRP 2014 citing Janssens et al. 2010, Knorr et al. 2005, and Melillo et al. 2011; Stockmann et al. 2013; Bardgett et al. 2013). Changes in these and other conditions can contribute to an increase or decrease in microbial growth which directly impact terrestrial carbon sequestration. For example, warmer soil temperatures have been shown to increase organic-matter decomposition rates thus increasing CO_2 emissions from soils (GCRP 2014). However, increased decomposition in soil increases release of essential plant nutrients (reactive nitrogen and phosphorus) which can increase plant growth thus increasing carbon sequestration (GCRP 2014 citing Melillo et al. 2011). Microbial growth is also affected by available nitrogen, particularly in cold, wet environments, and human introduction of nitrogen (mostly through application of fertilizer) could increase the decomposition of organic matter, increasing the release of CO_2 (IPCC 2013). The current annual exchange in CO_2 between the atmosphere and terrestrial ecosystems is estimated to be 9 to 10 times greater than annual emissions produced from burning fossil fuels. Even a small shift in the magnitude of this exchange could have a measurable

impact on atmospheric CO_2 concentration (Heath et al. 2005). Current models predict that warmer temperatures will result in overall losses of carbon sequestration in soils (Wieder et al. 2014) though there is debate over how accurately these models predict changes to soil microbial growth (Schimel 2013).

5.6.2.2.1 Effect of Elevated CO_2 Concentrations on Plant Growth

Bench- and field-scale experiments have shown that higher CO_2 concentrations have a fertilizing effect on plant growth (e.g., Long et al. 2006, Schimel et al. 2000) with considerable variability between regions (McGrath and Lobel, 2013). Compared to current CO_2 conditions, free air enrichment experiments with 550 ppm CO_2 (the amount predicted to be present by approximately 2050) yielded a 10 to 25 percent increase in growth of unstressed C3 crops (e.g., wheat, soybeans, and rice) and up to a 10 percent increase in growth of C4 crops (e.g., maize) (EPA 2009).[71] In addition, an IPCC review and synthesis of field and chamber CO_2 enrichment studies found that:

- Plants show a large range of responses, with woody plants consistently showing net primary productivity increases of 23 to 25 percent (Norby et al. 2005), and grain crops showing much smaller increases (Ainsworth and Long 2005).
- Overall, approximately two-thirds of the experiments show positive responses to increased CO_2 concentrations (Ainsworth and Long 2005, Luo et al. 2004).

It should also be noted that although CO_2 fertilization can result in a greater mass of available vegetation, it can also increase the carbon-to-nitrogen ratio in plants thus reducing plant nutrition. In one study, such fertilization of forage grasses for livestock increased their abundance but reduced their nutritional value, affecting livestock weight and performance (EPA 2009).

In addition to increases in growth rates for aboveground biomass, experiments have also shown that elevated CO_2 levels cause an increase in belowground net primary production and fine-root biomass (Madhu and Hatfield 2013, Pritchard 2011, Jackson et al. 2009 citing Fitter et al. 1995, Hungate et al. 1997, Matamala and Schlesinger 2000, King et al. 2001, Norby et al. 2004, Finzi et al. 2007). Studies have shown that under elevated CO_2 conditions, roots become more numerous, longer, thicker, and faster-growing with many species also showing increased root length (Madhu and Hatfield, 2013). For example, Jackson et al (2009) found that under elevated CO_2, roots showed a 24 percent increase of fine-root biomass in the top 15 centimeters (approximately 6 inches) of soil and a doubling of coarse-root biomass. Despite these increases, studies show that agricultural management practices have a greater impact on root growth than rising CO_2 levels (Madhu and Hatfield, 2013).

Because CO_2 stimulated growth is commonly limited by nutrients or other factors (Dukes et al. 2009, Körner et al. 2005), the magnitude and effect of CO_2 fertilization on plant growth under environmental conditions is not yet clear (McGrath and Lobel 2013). Easterling et al. (IPCC 2007) present studies suggesting that the CO_2 fertilization effect might be lower than previously assumed, with growth increases potentially limited by competition, disturbance (e.g., storm damage, forest fires, and insect infestation), air pollutants (primarily tropospheric ozone), nutrient limitations, ecological processes, and other factors (EPA 2009). McGrath and Lobel (2013) found that there is a strong regional effect on CO_2 induced yield increases likely due to regional differences in climate and the mixture of crops. Additionally, CO_2 fertilization only has a positive effect on plant growth over a limited range of

[71] C_3 and C_4 plants are differentiated by the manner through which they use CO_2 for photosynthesis, accounting for the differences in plant yield under similar ambient CO_2 conditions.

concentrations. Studies show that any increase in CO_2 concentration above 5 percent is likely to adversely impact vegetation (EPA 2009) and concentrations of 20 percent and higher have been shown to cause phytotoxic[72] effects (EPA 2009).

5.6.2.2.2 Effect of Elevated CO_2 Concentrations on Soil Microorganisms

Elevated CO_2 concentrations can affect soil microbial growth rates. In one study, an increase in CO_2 resulted in increased soil microbial respiration due to faster outputs and inputs, observed through amplified photosynthesis (Jackson et al. 2009 citing Canadell et al. 1995, Luo et al. 1996, Bernhardt et al. 2006, Gill et al. 2006, Hoosbeek et al. 2007, Wan et al. 2007). However, after 4 to 5 years of increased exposure to CO_2, "the degree of stimulation declined" to only a 10 to 20 percent increase in respiration over the base rate (King et al. 2004). Additionally, the degree of stimulation was linked to variability in seasonal and interannual weather (King et al. 2004), with root biomass, soil respiration, and other variables found to typically peak in midsummer and lessen in winter (Jackson et al. 2009). Increased soil respiration alters the concentration of CO_2 in soil pore spaces, which affects weathering of carbonates, silicates, and other soil minerals (Jackson et al. 2009 citing Sposito 1989, Andrews and Schlesinger 2001, Pendall et al. 2001, Karberg et al. 2005).

The increase in microbial respiration associated with elevated CO_2 concentrations could thus diminish the carbon sequestration role of terrestrial ecosystems. Elevated CO_2 levels were also found to significantly alter microbial community structure and composition, which could have significant impacts on soil carbon and nitrogen dynamics (He et al. 2010). Additionally, up-regulation of many of the genes involved in C decomposition in these communities could further impact the way microbial ecosystems regulate changes in CO_2 concentrations (He et al. 2010). However, a 2011 study suggests that although increasing atmospheric CO_2 positively affects root growth, it might not have any significant effect on soil microbes, simply because the increase is dwarfed by the amount of carbon already available to microbes in soil pore space (Pritchard 2011).

5.6.2.2.3 CO_2-Physiological Forcing

Elevated CO_2 concentrations have physiological impacts on plants, which can result in changes in both plant water utilization and local climate. A process referred to as "CO_2-physiological forcing" (Cao et al. 2010) occurs when increased CO_2 levels cause plant stomata (pores in plant leaves which allow for gas exchange of CO_2 and water vapor) to open less widely, resulting in decreased plant transpiration (Cao et al. 2010). Reduced stomata opening can result in a variety of effects. In terms of water utilization, reduced stomata opening increases water use efficiency in C3 and C4 plants, which can decrease canopy water use and increase soil moisture content, thus mitigating yield loss under drought conditions (McGrath and Lobel, 2013 citing Ainsworth and Rogers, 2007; Leakey 2009; Hunsaker et al. 2000; Conley et al. 2001; Leakey et al. 2006, Leakey et al. 2004, Bernacchi et al. 2007). In terms of climate change, reduction in canopy transpiration causes a decrease in evapotranspiration that triggers adjustments in water vapor, clouds, and surface radiative fluxes. These adjustments could ultimately drive macroclimatic changes in temperature and the water cycle (Cao et al. 2010). One study found that the physiological effects from a doubling of CO_2 on land plants resulted in 0.42 plus or minus 0.02°C (0.76 plus or minus 0.04°F) increase in air temperature over land and an 8.4 plus or minus 0.6 percent increase in global runoff (generally caused by reduced evapotranspiration). Furthermore, the study reported that a reduction in plant transpiration caused a decrease in relative humidity over land (Cao et al. 2010).

[72] Phytotoxicity is an abnormal adverse reaction of plants.

5.6.2.2.4 Ozone and Other Gases

Tropospheric ozone is mainly produced from NOx, CO and VOCs (GCRP 2014). Ozone has a negative effect on plant growth and biomass accumulation while CO_2 and ammonia (NH_3) act synergistically to increase plant growth (GCRP 2014). Nitrogen deposition drives temperate forest carbon storage by increasing plant growth by slowing organic-matter decomposition (GCRP 2014 citing Janssens et al. 2010, Knorr et al. 2005). Sulfur dioxide (SO_2) is expected to reduce plant growth through the leaching of soil nutrients and increasing of radiative forcing (GCRP 2014).

5.6.2.2.5 Higher Temperatures

Climate induced increases in temperature will have both positive and negative impacts on carbon storage in plants and soils. For example, higher temperatures increase decomposition rates thereby increasing CO_2 emissions from microbial respiration. However, increased decomposition rates also accelerate the release of reactive nitrogen (and phosphorus) from organic matter, which can spur additional plant growth (GCRP 2014 citing Melillo et al. 2011). Plant net primary productivity (NPP) [73] is affected by temperature, and the combined effects of ecosystem carbon storage will depend on the extent to which nutrients constrain both net primary productivity and decomposition, on the extent of warming, and on whether any simultaneous changes in water availability occur (GCRP 2014 citing Dijkstra et al. 2012; Schimel et al. 2001, Wu et al. 2011).

<u>Longer Growing Season</u>

The frost-free season (and corresponding growing season) has been increasing since the 1980s with the largest increase occurring in the western United States. This change is affecting ecosystems and agriculture across the United States and is projected to continue to lengthen (GCRP 2014). A longer growing season provides a longer period of plant growth and productivity which can slow the increase in atmospheric CO_2 concentrations through increased biogenic uptake of CO_2 (GCRP 2014 citing Peñuelas et al. 2009). A 6 percent increase in global NPP, or the accumulation of 3.4 petagrams of carbon (PgC), was observed in satellite greenness on land from 1982 to 1999 (IPCC 2013 citing Nemani et al. 2003; IPCC 2013). This trend was attributed to increased plant growth in high latitudes (IPCC 2013). Increased NPP due to warming was partially offset by global soil respiration which also increased between 1989 and 2008, reducing the magnitude of the net land sink (IPCC 2013 citing Bond-Lamberty and Thomson 2010).

Overall, there is *high confidence* that climate change effects on crop production are evident in several regions of the world and negative trends are more common than positive ones (IPCC 2014). There is *high confidence* that CO_2 has overall stimulatory effects on crop yields, that elevated tropospheric ozone has negative effects on crop yields and *medium confidence* that due to interactions between CO_2, O_3, mean temperatures, extremes, water and nitrogen their overall effects on crop yields difficult to predict (IPCC 2014). There is currently *high confidence* that biomass and soil carbon stocks are currently increasing, but are vulnerable to future loss to the atmosphere due to rising temperatures, drought and fire projected in the 21st century (IPCC 2014).

[73] The total amount of CO_2 stored by a plant through photosynthesis minus the amount released through respiration.

CHAPTER 6 LIFE-CYCLE IMPACT ASSESSMENT OF VEHICLE ENERGY, MATERIALS, AND TECHNOLOGIES

6.1 Introduction

The International Organization for Standardization (ISO) defines a Life-Cycle Assessment (LCA) as the "compilation and evaluation of the input, output, and potential environmental impact of a product system throughout its life cycle" (ISO 2006). Like any product, a vehicle's LCA impacts do not accrue exclusively during the time it spends in use (i.e., they are not limited to engine exhaust emissions and evaporative emissions). Each stage of a vehicle's life cycle, including vehicle fuel production, contributes to GHG emissions, energy use, and other environmental impacts.

NHTSA recognizes that life-cycle considerations inform decisionmakers in this rulemaking. Air quality and climate impacts reported in Chapters 4 and 5 include upstream emissions resulting from the use, leakage, spillage, and evaporation of fuels during feedstock production (e.g., crude oil or natural gas [NG]); feedstock transportation (to refineries or processing plants); fuel refining and processing (into gasoline, diesel, dry NG, and NG liquids); and refined product transportation (from bulk terminals to retail outlets). These upstream emissions included in Chapters 4 and 5 account for less than 20 percent of total GHG emissions and less than 10 percent of most non-GHG emissions (the percentage is higher for some specific pollutants). Air quality and climate impacts reported in Chapters 4 and 5, however, include only emissions associated with the vehicle fuel life-cycle. Therefore, Chapters 4 and 5 do not include any estimated life-cycle impacts associated with HD vehicle materials or technologies themselves that might be applied to improve fuel efficiency, including emissions related to vehicle manufacturing.

A complete LCA of the impacts of this rulemaking, which is beyond the scope of this EIS, would require extensive information about many variables that are highly uncertain, including the future behavior of HD vehicle manufacturers in response to the proposed standards, the specific design of multiple fuel efficiency technologies (and how they are applied to vehicles), interactions between application of those technologies, and specific details on the variety of vehicle types, manufacturers, and uses expected in the future. HD vehicle standards are performance-based rather than technology-mandating. As a result, NHTSA does not know precisely how manufacturers will choose from a suite of available technologies to meet the proposed standards. Instead, NHTSA is presenting a literature synthesis of existing credible scientific information relevant to evaluating the potential environmental impacts of the Proposed Action and alternatives. This literature synthesis is presented below in four sections:[1]

- The remainder of Section 6.1 provides background on applying LCA methods to HD vehicles.
- Section 6.2 examines LCA impacts associated with different HD vehicle fuels.
- Section 6.3 examines LCA impacts associated with HD vehicle materials and technologies.
- Section 6.4 presents conclusions from this literature synthesis.

[1] By including this chapter on LCA in this EIS, NHTSA does not mean to imply that vehicle manufacturers should be held responsible for the environmental impacts that accrue at every stage of a vehicle's life cycle. The impacts are included here to inform decisionmakers and the public about certain broader environmental implications of the rulemaking action.

This chapter does not attempt to provide a comprehensive review of all LCA studies related to HD vehicles, but rather it focuses on recent studies that provide more background on upstream emissions already incorporated in the analyses in Chapters 4 and 5, as well as the material and technology LCA impacts not reflected in the analyses in Chapters 4 and 5. The main purpose of this literature synthesis is to supplement quantitative analysis of alternatives reported in Chapters 4 and 5.

6.1.1 Overview of Life-Cycle Assessment in the Vehicle Context

Activities at each stage of a vehicle's life cycle contribute to emissions of GHGs, energy use, and other environmental impacts. For example, mining and transporting ore requires energy (usually in the form of fossil fuels), as does transforming ore into metal, shaping the metal into parts, assembling the vehicle, driving and maintaining the vehicle, and disposing of and/or recycling the vehicle at the end of its life. Recycling vehicle components can save energy and resources and can reduce emissions by displacing the production of virgin materials (e.g., ore, crude oil), but even recycling requires energy and produces emissions. Vehicle LCAs typically evaluate environmental impacts associated with five primary stages: raw-material extraction, manufacturing, vehicle use, end-of-life management, and transportation between these various stages. Raw-material extraction includes the mining and sourcing of material and fuel inputs. Manufacturing often consists of sub-stages, including material and part production and vehicle assembly. The use stage typically comprises two sub-stages: the driving sub-stage (e.g., fuel combustion) and maintenance (e.g., part repair or replacement). End-of-life management can include such steps as parts recovery, disassembly, shredding, recycling, and landfilling.

An LCA study can help determine whether certain materials and technologies save energy over the entire life cycle of vehicles, keeping other factors (e.g., miles traveled, tons of freight carried, vehicle life) equal. Changes in the material composition of vehicles could decrease the emission potential of the use stage but increase that of the raw material extraction and manufacturing stages (Geyer 2008). On the other hand, because of the high proportion of total emissions during the use stage, the fuel-saving benefits realized during a vehicle's use due to improved fuel economy could very likely outweigh the additional energy investment associated with material changes (Cheah et al. 2009).

LCA allows users to evaluate the environmental impacts of different vehicle technologies on an equal basis within a given study, but LCAs vary greatly in their scope, design, data sources, and assumptions, making it challenging to compare results between studies. In setting the scope of each study, LCA practitioners decide on the unit of measure, life-cycle boundaries, environmental impact categories to consider, and other factors that address the defined purpose of the study. Most studies in this literature synthesis evaluate different types of vehicles with different assumptions for vehicle weight, vehicle life, and miles traveled underlying the functional unit. In terms of impacts, some studies include those across the entire cradle-to-grave life cycle (i.e., from resource extraction through end of life), including impacts from extraction of all energy and material inputs. Others include impacts only from cradle to [factory] gate (i.e., from resource extraction through manufacturing and assembly, but excluding vehicle use and end of life). Most of the studies evaluate energy use and climate change impact measured by GHG emissions, but several also include other environmental impact categories (e.g., acidification, eutrophication, odor and aesthetics, water quality, landfill space, ozone depletion, particulates, solid and hazardous waste generation, and smog formation). Data availability often influences the boundaries and impacts included.

LCA practitioners decide how to assign or allocate environmental impacts between the functional unit (i.e., the product under study) and other co-products produced by the system.[2] For example, scrap material can perform functions after its use in an HD vehicle. Studies that consider scrap flows outside the vehicle life-cycle boundary might: (1) allocate a portion of the impacts associated with vehicle manufacture or recycling to the scrap flow, (2) treat scrap as a waste flow and not allocate any impacts to it, or (3) expand the system to include the scrap output flow within the system boundary. The varying treatment of scrap material and other LCA aspects and assumptions in each study limits the comparability of the results.

For some of the studies considered in this chapter, the authors used existing models to assess life-cycle emissions. Other studies included independent assessments of life-cycle implications using study-specific models developed from life-cycle inventory data sources such as the ecoinvent database.[3] The most commonly used model in the surveyed literature was GHGs, Regulated Emissions, and Energy Use in Transportation (GREET) model, a public-domain model developed at Argonne National Laboratory (ANL) that allows users to estimate life-cycle energy and emissions impacts on a full fuel-cycle and vehicle life-cycle basis. ANL developed GREET in 1996 and has updated the model to reflect recent data, new fuel pathways, and vehicle technologies. GREET uses a process-based approach wherein the model calculates life-cycle results by modeling the various processes and technologies used to extract, refine, and distribute fuels, and to manufacture, use, and dispose of vehicles. The upstream emissions included in the air quality and climate impacts reported in Chapters 4 and 5 of this EIS are estimates based on information from GREET.

In addition, several studies used the Economic Input-Output LCA Model developed by Carnegie Mellon University's Green Design Institute. The model is not specific to fuel and vehicle LCA, but it can be used to estimate the energy and emissions impacts of components, materials, and industries involved in the vehicle component manufacturing supply chain. The Green Design Institute periodically updates the model to reflect new input-output data and impact characterization data and methods. The Economic Input-Output LCA Model assumes that GHG emissions are linked to economic flows through different sectors. Therefore, unlike GREET, the model is not process-based; it is most applicable to assessing impacts from an industry sector (e.g., vehicle manufacturing) rather than specific products (e.g., a specific vehicle make or model).

Some studies used the Mobile Source Emission Factor (MOBILE) model—which calculates gram-per-mile emissions of hydrocarbons, carbon monoxide, nitrogen oxides (NO_x), carbon dioxide (CO_2), particulate matter, and toxics from vehicles—to refine estimates of pollution from the use phase of vehicles. MOBILE is not a life-cycle model; rather, it focuses only on emissions from vehicles during the use phase. Data in MOBILE are based on emissions testing of vehicles and account for several factors, including changes in vehicle emission standards, changes in vehicle populations and activity, and variation in local conditions, such as temperature, humidity, and fuel quality. MOBILE, which was developed and updated by EPA from 1978 to 2010, has since been replaced by EPA's Motor Vehicle Emission Simulator (MOVES).

Because LCAs are highly sensitive to design and input assumptions, their results reflect variation in impacts. Despite study differences, based on the studies considered for this synthesis, it is clear that

[2] ISO advises that LCAs avoid allocation by dividing the process into separate production systems or through system expansion, including the additional co-product functions (ISO 2006).

[3] Life-cycle inventory data is information on the inputs, outputs, and potential environmental impacts of a product or process. The ecoinvent database, managed by the Swiss Centre for Life Cycle Inventories, is a large source of life-cycle inventory data on products and processes from different countries around the world, including the United States.

most energy is consumed and most GHGs are emitted during the vehicle use stage. Hakamada et al. (2007) estimate that this stage accounts for approximately 80 percent of the life-cycle vehicle GHG emissions in conventional internal combustion engine vehicles, which is consistent with the vehicle use share of GHG emissions reflected in the analysis in Chapter 5. The manufacturing stage is the second most energy- and GHG-emission-intensive LCA stage, accounting for 5 to 15 percent of total vehicle life-cycle GHG emissions (Geyer 2008, Hakamada et al. 2007).

6.1.2 Approach to HD Vehicle Life-Cycle Assessment Literature Synthesis

NHTSA performed research to identify studies across a range of sources, including academic journals and publications of industry associations and non-governmental organizations. Appendix D lists all of the studies reviewed. Most of the studies identified were published within the last 10 years. NHTSA prioritized literature published in the last 2 years and LCAs specifically focused on HD vehicles and technologies, and NHTSA incorporates by reference the related LCA literature synthesis for light-duty vehicles reported in Chapter 6 of the *Final Environmental Impact Statement for Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks, Model Years 2017–2025* (the MY 2017–2025 CAFE standards Final EIS) (NHTSA 2012). The LCA literature shows general consistency in the findings between studies focused on HD vehicles and those focused on light-duty vehicles. Where findings are likely transferable to HD life-cycle considerations, light-duty studies further support the limited findings focused solely on HD vehicles.

6.1.3 Comparability of Life-Cycle Assessment Findings by HD Vehicle Type

The comparability of some LCA findings related to HD vehicles is made more complex due to the various types of HD vehicles in the national fleet and the applicability of different fuel-saving technologies. In addition to having more than one type of vehicle in a gross vehicle weight rating (GVWR) class, various types of vehicles can fall under one or more classes. For example, a city delivery van can fall under Classes 3, 4, or 5, depending on its weight. This section identifies general variations in LCA impacts among vehicle classifications and usage.

The life-cycle impacts of different sized vehicles are best compared using an appropriate functional unit. For vehicles that haul weights short distances, such as loaders, comparison on emissions per mile or per ton-mile will not be comparable to other vehicle classifications that are more focused on long-haul transportation. For these HD vehicles, the use-phase energy consumption is closely correlated with the weight of the vehicles and of the load. As an example, wheel loaders move heavy weight from one place to another; therefore, a functional unit of weight of stockpiled materials being moved and deposited is an appropriate functional unit (Salman and Chen 2013). Technologies that focus on aerodynamics or material substitution may not have much impact on the life-cycle impacts from wheel loaders, but technologies that decrease diesel consumption over the lifetime of the vehicle will. In the study by Salman and Chen, the authors show that a hybrid-powered L150G loader would have low CO_2 emissions during all phases by virtue of replacing some diesel consumption with electricity consumption from the grid. While these results are based on an analysis of off-road vehicles that are not covered under the current rule, NHTSA expects that the same impacts would apply for HD vehicles.

In freight transport, both the truck weight and the freight weight influence the life-cycle impacts of the vehicle. Therefore the functional unit of choice in LCAs is the ton-mile, which expresses the impacts of fuel efficiency with regard to freight carried. As the payload increases, the emissions on a ton-mile basis generally decrease. For example, Facanha and Horvath (2007) estimate that the CO_2 emissions from a Class 2b (1.6 tons payload) freight vehicle average 289 grams (g) CO_2 per ton-mile, while emissions from

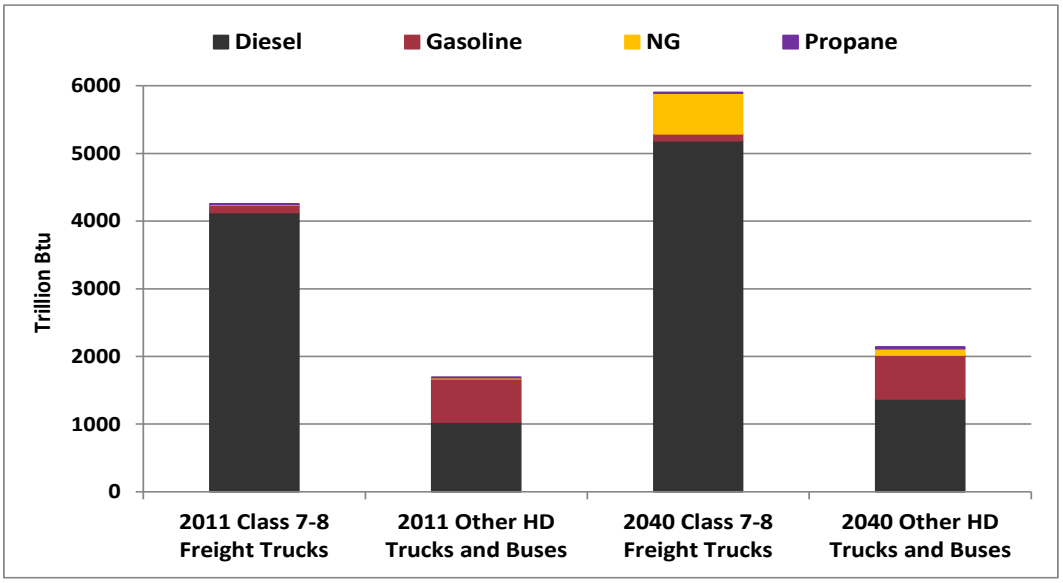
a Class 5 (3.1 tons payload) freight vehicle average 230 g CO_2 per ton-mile, and emissions from a Class 8b (12.5 tons payload) freight vehicle average 187 g CO_2 per ton-mile.

6.2 Energy Source Life-Cycle Considerations

As discussed above, air quality and climate impacts reported in Chapters 4 and 5 include tailpipe emissions and upstream emissions from the production, processing, and distribution of fuels. To provide a point of reference, this section begins with a summary of the Annual Energy Outlook (AEO) 2014 forecast for HD fuel use because analyses reported in Chapters 4 and 5 are based on HD fuel forecasts consistent with AEO 2014. LCA literature on the types of energy consumed by HD vehicles and their LCA impacts are discussed in Sections 6.2.1 through 6.2.3. In the discussion that follows, emissions during use as well as upstream life cycle stages are considered for all HD vehicle energy sources.

Figure 6.2-1 shows that Classes 7–8 freight trucks account for about two-thirds of total HD vehicle fuel use. Fuel use by Classes 7–8 trucks in 2011 was 97 percent diesel, 2.6 percent gasoline, 0.3 percent liquefied petroleum gas (LPG, commonly referred to as propane), and 0.1 percent NG. Fuel use by buses and Classes 2b–6 trucks in 2011 was 60.8 percent diesel, 37.7 percent gasoline, 1.1 percent NG, and 0.4 percent LPG. AEO 2014 forecasts that diesel and gasoline will still be the dominant fuels used by HD vehicles in 2040, but the NG share of HD vehicle fuel is forecast to increase to 10.1 percent for Classes 7–8 trucks and 4.4 percent for other HD vehicles. Figure 6.2-2 shows that transit buses account for most of the AEO 2014 forecast growth for NG use by buses and Classes 2b–6 trucks in 2040.

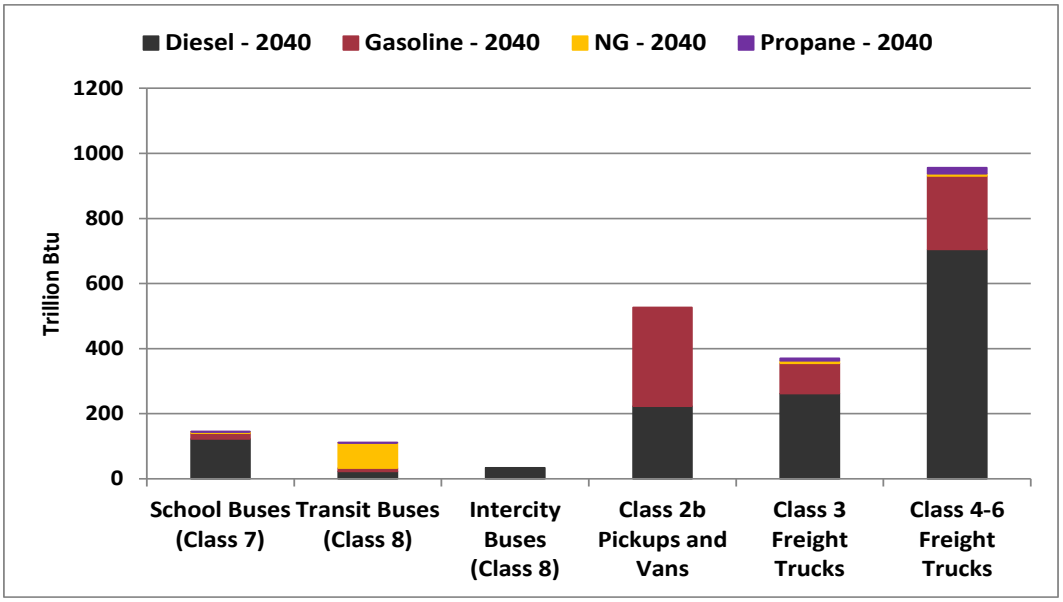
Figure 6.2-1. U.S. HD Vehicle Energy Consumption by Source and Vehicle Type in 2011 and 2040



Source: EIA 2014d.

Btu = British thermal units; HD = heavy duty; NG = natural gas

Figure 6.2-2. Forecast 2040 Fuel Use in Buses and Classes 2b–6 Trucks



Source: EIA 2014d.
Btu = British thermal units; NG = natural gas

Ethanol is now common in gasoline blending; the HD vehicle gasoline consumption shown in Figures 6.2-1 and 6.2-2 includes up to 10 percent ethanol content. The AEO 2014 also forecasts a substantial increase in E85 (85 percent ethanol) fuel use by light-duty vehicles, but negligible E85 use by HD vehicles. Diesel consumption in Figures 6.2-1 and 6.2-2 also includes a small amount of biodiesel blended with diesel from petroleum, but biodiesel is forecast to account for less than 3 percent of total diesel use through 2040. The AEO also forecasts an increase in grid electricity use by plug-in light-duty vehicles, but negligible grid electricity use by HD vehicles. Hybrid-electric engines can be an economical means of improving the fuel efficiency of some HD vehicles, but hybrid vehicles also use gasoline, diesel, NG, and/or LPG and are, therefore, included in Figures 6.2-1 and 6.2-2 forecasts for those fuels consumed by HD vehicles. Due to the negligible forecast use of grid electricity by HD vehicles, this section does not review LCAs that focus on upstream emissions from electric power plants. An extensive discussion of electric generation emissions associated with plug-in vehicles can be found in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS.

The remainder of this section synthesizes life-cycle findings with regard to the following types of fuel sources for HD vehicles: diesel and gasoline, NG, and biofuels. LPG is primarily used in transit buses, and there is a lack of published LCA studies on other LPG vehicle applications due to relatively low use. Despite the relatively small current and projected use of NG, this section presents a more extensive discussion of LCA studies related to NG than petroleum, because the literature reveals more uncertainty on LCA impacts of NG vehicles and greater consensus on upstream emissions from petroleum production and refining. The synthesis of LCA studies related to biofuels is also relatively brief because the AEO 2014 does not forecast substantial changes in biofuel use, and this rulemaking is not expected to have a large impact on the extent of biofuel use.

6.2.1 Diesel and Gasoline

As noted above, the analyses in Chapters 4 and 5 include upstream and point-of-use fuel emissions, and the upstream percent of total emissions is consistent with LCA studies indicating that point-of-use fuel

emissions account for approximately 80 percent of life-cycle vehicle GHG emissions in conventional internal combustion engine vehicles. These concordant findings reflect general consensus on upstream emissions associated with conventional oil production and refining, but there is less consensus on LCA impacts of unconventional sources of petroleum, including shale oil produced by advanced well completion processes involving fracturing (fracking) and petroleum from oil sands. Life-cycle considerations associated with fracking are similar for shale oil and for shale gas, and the LCA synthesis in Section 6.3, which focuses on shale gas, also addresses LCA considerations associated with shale oil. Therefore, the remainder of this section focuses on oil sand issues.

Oil sands, also known as tar sands or bituminous sands, are a mixture of sand and clay saturated with a thick blend of hydrocarbons. The United States predominantly imports oil sands–derived crude oil from Canada (Canadian National Energy Board 2014). Gasoline and diesel produced from oil sands can be substituted for gasoline and diesel produced from conventional sources without any modifications to vehicle equipment or changes in performance. From a life-cycle perspective, the sole difference occurs upstream in the life cycle during extraction and processing, resulting in additional GHGs and environmental impacts. As of 2013, the United States consumed 1.2 million barrels per day of oil sands–derived crude oil out of a total 18.9 million barrels of daily petroleum consumption, but this share is expected to increase as a result of new projects coming online (Canadian National Energy Board 2014).

A variety of studies have been published evaluating the well-to-wheels emissions associated with petroleum from oil sands, reaching a consensus that oils sands petroleum is more GHG-intensive to produce than conventional counterparts because oils sands require more energy to extract and process. Oil sands also have comparatively less hydrogen but contain higher amounts of impurities that require more energy-intensive processing prior to end use (Lattanzio 2014).

In addition to upstream GHG emissions from extraction and processing, the mining process for oil sands also impacts land to a higher degree than conventional oil extraction. Surface mining involves land clearance and extraction of shallow deposits, and in-situ recovery involves drilling wells and injecting steam underground to reduce bitumen viscosity. One study showed that land disturbance in Alberta ranges from 1.6 to 7.1 hectares per well pad, averaging 3.3 hectares. These impacts are significantly higher than land disturbance for conventional oil drilling in California, which averages 1.1 hectares per well (Yeh et al. 2010). Furthermore, land disturbance for oil sands extraction in Alberta has been shown to impact peat deposits, which results in additional life-cycle GHG emissions regardless of reclamation efforts. Changes in soil carbon stocks, biomass removal from surface mining, and in-situ extraction of oil sands in Alberta emit 3.9 g and 0.04 g of CO_2 equivalent per megajoule (MJ) of energy.

The U.S. State Department commissioned a study for the Keystone XL pipeline project in both the 2011 Final Environmental Impact Statement and 2014 Final Supplemental Environmental Impact Statement, comparing the incremental GHG emissions associated with the pipeline to a selection of "reference crudes," defined as conventional crude oils available on the U.S. market. On a per-MJ basis, the well-to-wheels GHG emissions from Canadian oil crudes are 17 percent higher than those from the "average" barrel of crude oil sold in the United States (U.S. State Department 2014). Most of this increase comes from the extraction and refining phase; the well-to-tank (i.e., upstream production) GHG emissions from oil sands crudes are 9 to 102 percent higher than emissions from conventional crudes (Lattanzio 2014).

The National Energy Technology Laboratory (NETL) estimated the total lifecycle impact from diesel fuel production and use. NETL used 2005 for the analysis year, and the research report provides the most recent available findings. EPA developed GHG emissions estimates, expressed as CO_2 equivalent, by summing NETL's CO_2 emissions estimates with methane and nitrous oxide estimates derived from the EPA MOVES vehicle emissions modeling tool. Table 6.2.1-1 shows the combined results with a total of 97,306 grams per million British thermal units (Btu).

Table 6.2.1-1. Estimated Diesel Fuel Lifecycle Greenhouse Gas Emissions (g/million Btu)

	Carbon Dioxide	Methane[a]	Nitrous Oxide[a]	CO_2e Totals
Well to Tank	15,838	2,450	89	18,377
Tank to Wheels	78,308	25	596	78,929
Well to Wheels	94,146	2,475	685	97,306

Notes:
[a] The values are calculated using 25 and 298 for the global warming potentials for methane and nitrous oxide, respectively.
Source: EPA 2015.
Btu = British thermal unit

6.2.2 Natural Gas

NG can be used in vehicles as compressed natural gas (CNG) or liquefied natural gas (LNG), and there is considerable interest in and uncertainty about the extent to which NG could become widely used in HD vehicles, specifically in Classes 7–8 freight trucks, which account for more than 80 percent of total Classes 3–8 freight truck fuel use (excluding bus fuel use). CNG in HD vehicles has advantages over LNG due to simplified distribution logistics with fewer opportunities for emissions leakage. However, LNG has 60 percent the energy density of conventional diesel versus 25 percent for CNG. Due to the higher energy density, LNG is likely favored for use in long-haul trucking (EPA 2015). AEO 2014 forecasts that the NG share of new Classes 7–8 freight truck sales will fall from 1.2 percent in 2013 to 0.3 percent in 2017–2020, and then increase to 1.3 percent by 2025 and 11.3 percent in 2040. A recent study (Heath et al. 2014) cites other forecasts that NG vehicles could account for 20 to 40 percent of new Class 8 vehicle sales as early as 2020.

EPA recently conducted lifecycle analysis for natural gas-fuel HD vehicles and compared results with diesel fuel HD vehicles. Four scenarios were considered to evaluate both CNG and LNG HD vehicles. All scenarios included methane and nitrous oxide emissions. The scenarios also included a NG "thermal efficiency" factor. Thermal efficiency refers to the additional fuel required with NG from a lower engine compression ratio compared to conventional diesel. Natural gas powered engines require more fuel to compensate and move a vehicle the same distance. Driver behavior also influences thermal efficiency. Thermal efficiency is not an actual emission source, yet it plays a role in an HD vehicle's emissions and is thus considered within the life cycle assessment (EPA 2015). Each of the scenarios includes a low and high thermal efficiency rating of 5 and 15 percent.

The first scenario evaluates conversion of existing diesel trucks, not subject to the 2014 methane standard, to run on CNG. Ninety percent of HD vehicles fueled by natural gas and currently in use are this type. In Scenario 1 the lower well to wheels total is 88,837 g/million Btu and the higher total is 96,336 g/million Btu. These emissions levels are 1 to 4 percent lower than conventional diesel emissions cited in Table 6.2.2-1 at 97,306 g/million Btu (*see* Scenario 1 CNG emissions values in Table 6.2.2-2).

The second scenario is for current and future HD vehicles subject to the 2014 methane standard. For the 2014 and newer HD CNG vehicles in this scenario, the lower well to wheels total is 79,212 g/million Btu and the higher total is 86,547 g/million Btu. These emissions levels are 11 to 18 percent lower than conventional diesel emissions cited in Table 6.2.2-1 *(see* Scenario 2 CNG emissions values in Table 6.2.2-2).

The third scenario is for LNG powered trucks with low venting and low boil-off emissions. LNG is more likely for long haul trucking given its higher energy density as compared to CNG. Venting LNG to the atmosphere occurs when HD vehicle operators refuel and need to decrease the pressure in the fuel tank

before additional fuel can be added. The recommended procedure is to transfer any remaining vaporized fuel back to the gas station or NG pipeline. Given regularly occurring delivery time pressures, HD operators may choose to vent the extra LNG to the atmosphere. LNG "boil-off" emissions occur when the fuel in a HD vehicle or retail facility storage tank warms the NG, which reaches the relief venting pressure threshold. In Scenario 3 the lower well to wheels total is 93,384 g/million Btu and the higher total is 102,123 g/million Btu. These emissions levels are either 4 percent lower or 5 percent higher depending on the thermal efficiency factor when compared with conventional diesel emissions cited in Table 6.2.2-1 (*see* Scenario 3 LNG emissions values in Table 6.2.2-2).

Table 6.2.2-2. Full Life Cycle Analysis Scenarios for CNG/LNG HD Vehicles (g/million Btu)

Fuel type and Scenario	Life Cycle Range	Carbon Dioxide	Methane[a]	Nitrous Oxide[a]	Thermal Efficiency 5% CO_2e	CO_2e Totals (including 5% therm. efficiencies)	Thermal Efficiency 15% CO_2e	CO_2e Totals (including 15% therm. efficiencies)
Scenario 1 (**CNG** pre-2014 truck)	Well to Tank	7869	6225	21	705	14,812	2116	16,223
	Tank to Wheels	60,891	9500	596	3044	74,033	9134	80,123
	Well to Wheels	68,760	15,700	596	3750	88,837	11,249	96,336
Scenario 2 (**CNG** 2014 or later truck)	Well to Tank	7869	6225	21	705	14,812	2116	16,223
	Tank to Wheels	60,704	125	596	3044	64,480	9134	70,570
	Well to Wheels	68,574	6350	596	3668	79,212	11,003	86,547
Scenario 3 (**LNG** low vent and boil-off emissions)	Well to Tank	20,405	6275	3.0	1334	28,017	4002	30,685
	Tank to Wheels	60,707	1000	596	3035	64,474	9106	70,545
	Well to Wheels	81,113	7275	596	4370	93,384	13,109	102,123
Scenario 4 (**LNG** high vent and boil-off emissions)	Well to Tank	20,405	6275	3.0	1334	28,017	4002	30,685
	Tank to Wheels	60,707	24,750	596	3035	89,072	9106	95,143
	Well to Wheels	81,113	24,750	596	4370	117,090	13,109	125,829

Notes:

[a] The CO_2e totals are calculated using 25 and 298 for the global warming potentials for methane and nitrous oxide, respectively.

Source: EPA 2015.

Btu = British thermal unit

The fourth scenario is for LNG powered HD vehicles with high venting and high boil-off emissions. In Scenario 4 the lower well to wheels emissions total is 117,090 g/million Btu and the higher total is 125,829 g/million Btu. These emissions levels are either 20 or 29 percent higher than conventional diesel emissions cited in Table 6.2.2-1 (*see* Scenario 4 LNG emissions values in Table 6.2.2-2).

Section 6.2.2.1 summarizes literature assessing the impacts of upstream methane (CH_4) leakage associated with NG. Section 6.2.2.2 examines literature on shale gas production and hydraulic fracturing in more detail.

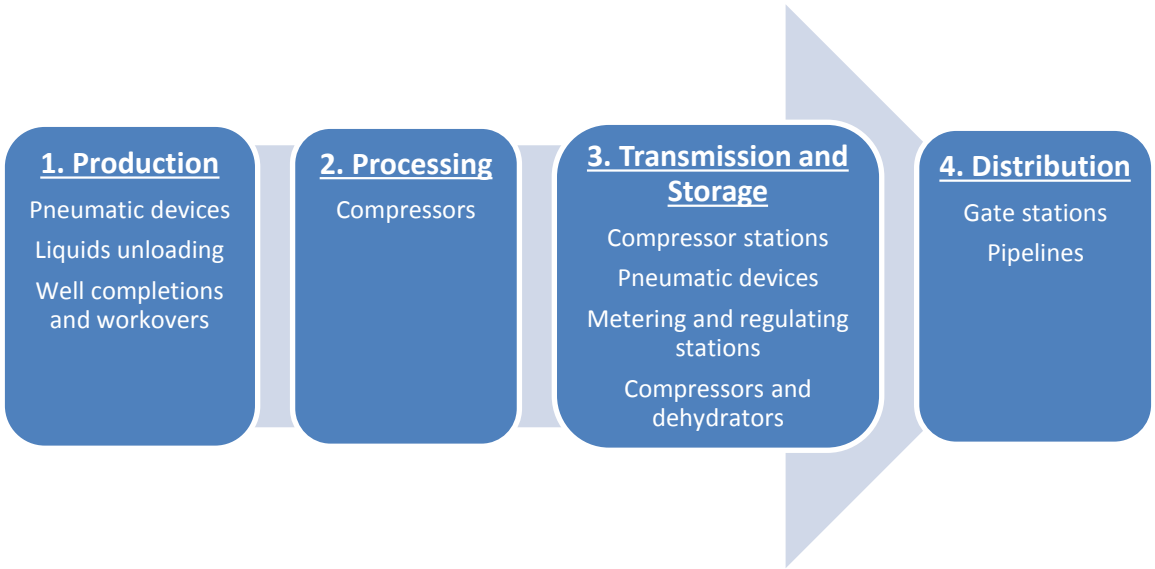
6.2.2.1 Methane Leakage

CH_4 accounts for an estimated 9 percent of total U.S. GHG emissions on a CO_2 equivalent basis. Between 1990 and 2012, annual CH_4 emissions decreased by 11 percent, largely as a result of emission reductions from an EPA rule regulating landfills (Executive Office of the President 2014, EPA 2014a). However, in the United States annual total CH_4 emissions are projected to increase to approximately 8,570 million metric tons CO_2e ($MMTCO_2$e) by 2030; this is a 26 percent increase in annual emissions as compared to 2005 (EPA 2012). To this end, a key highlight of the June 2013 Executive Office of the President's Climate Action Plan is to address and reduce CH_4 from four key sources: landfills, coal mines, agriculture, and oil and NG systems (Executive Office of the President 2013). Approximately 25 percent of the CH_4 emitted in the United States is attributed to NG systems, the second largest source of anthropogenic CH_4 emissions (EPA 2014a) after enteric fermentation (gas emitted by livestock).

CH_4 emissions occur at multiple points upstream of the end use of NG for industrial, power generation, and transportation purposes. NG systems consist of four major stages: production (i.e., extracting the NG), processing, transmission and storage, and distribution. CH_4 leakage occurs at a variety of points in these four stages.

Figure 6.2.2-1 identifies the main sources of CH_4 emissions during each of the upstream stages prior to NG consumption. EPA estimates that in 2012, the United States emitted 129.9 $MMTCO_2$e of CH_4 from upstream NG systems, of which 32 percent was from field production, 14 percent was from processing, 34 percent was from transmission and storage, and 20 percent was from distribution (EPA 2014a). These emissions do not include emissions related to use of NG (i.e., combustion of NG in vehicles).

Figure 6.2.2-1. Main Sources of Methane Leakage during Upstream Life-cycle Stages: Natural Gas Production, Processing, Transmission and Storage, and Distribution



The main sources of CH_4 emissions during production are pneumatic devices,[4] liquids unloading, and gas completions and workovers with and without hydraulic fracturing (EPA 2014a). Raw NG is composed of CH_4 as well as other impurities. These impurities must be removed before the NG can be transported to prevent pipeline corrosion and in order for the NG to serve its end-use purpose. At processing facilities, the NG is separated from the other constituents of the raw gas. This requires maintaining certain levels of pressure during processing, and during the processing stage CH_4 emissions arise mainly from compressors (EPA 2014a). This processed gas is then sent to transmission systems to be transported to distribution systems, and hence to end-use consumption. In some instances the processed product is stored in underground formations or liquefied and stored above ground in tanks. Storage occurs during periods of low demand, and the NG is distributed during times of high demand. During transmission, CH_4 emissions mainly arise from the compressor stations, pneumatic devices, and from metering and regulating stations. When NG is stored, it can leak from compressors and dehydrators. During distribution, NG is emitted mainly from the gate stations and pipelines (EPA 2014a).

There has been recent increased market penetration of NG in the industrial, power, and transportation sectors, associated with increased United States production of NG in large part due to development of shale gas resources (Figure 6.2.2-2), which has resulted in lower prices. During the use stage, NG results in lower GHG emissions per unit of energy than other fossil fuels (US EIA 2014a, 2014b). However, some argue that NG is not a better climate solution when considering the short-term GHG life-cycle perspective. A 2012 article in the Proceedings of the National Academy of Sciences states, "Recent reports in the scientific literature and popular press have produced confusion about the climate implications of natural gas. On the one hand, a shift to natural gas is promoted as climate mitigation because it has lower carbon per unit energy than coal or oil. On the other hand, methane, the prime constituent of natural gas, is itself a more potent GHG than CO_2; methane leakage from the production, transportation and use of natural gas can offset benefits from fuel-switching" (Alvarez et al. 2012).

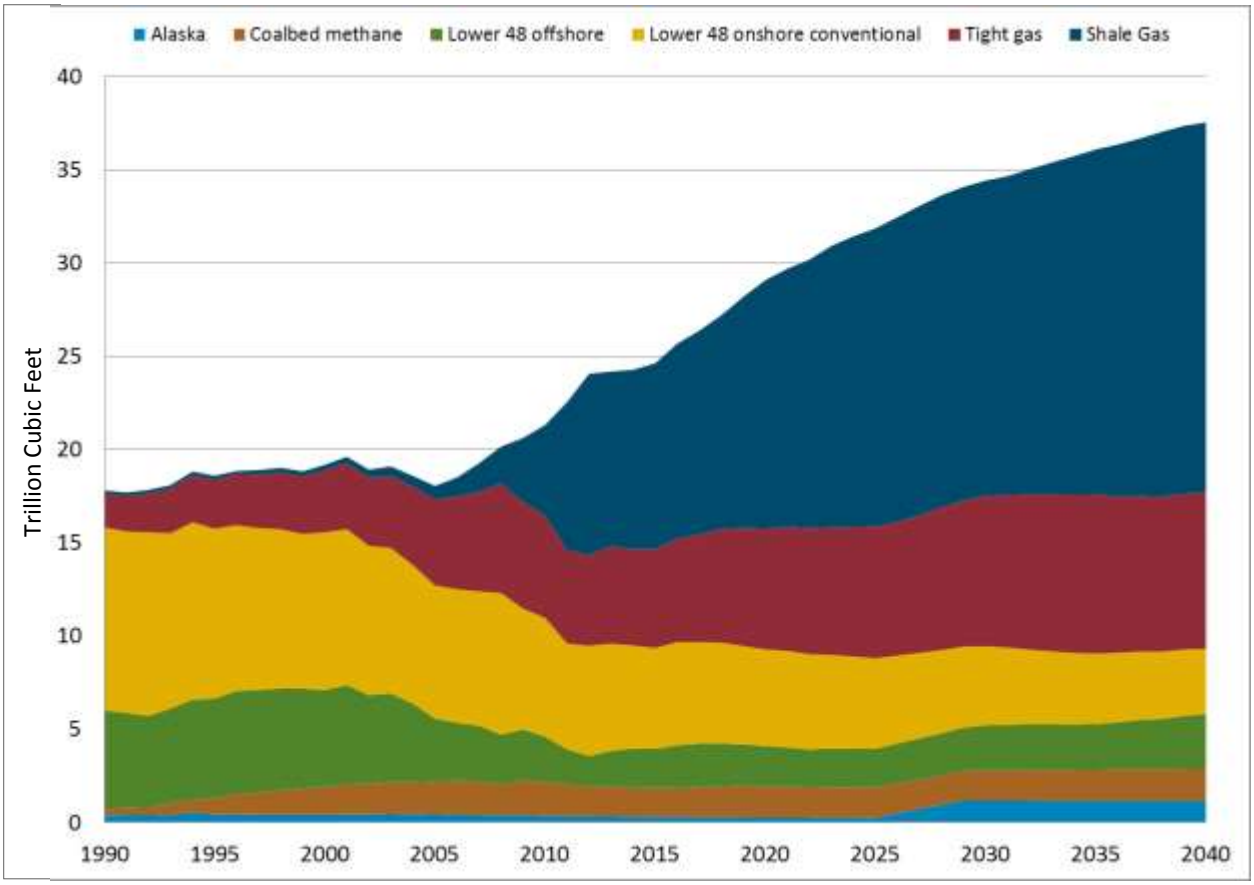
There has been a wealth of recent research and literature around quantifying CH_4 leakage and understanding how to address this leakage. Some studies suggest that CH_4 leakage associated with NG extraction is higher than is accounted for in the U.S. national GHG emissions inventory.[5] Hamburg (2013) and Petron et al. (2012) assert that fugitive CH_4 leakage at NG extraction sites is likely undercounted. At the end of the pipeline distribution system, several studies find that CH_4 leakage can occur in multiple locations near the point of use, although these emissions are highly variable and difficult to quantify (Jackson et al. 2014, Payne and Ackley 2012, Peischl et al. 2013, Phillips et al. 2012).

From the standpoint of comparing life-cycle electric utility emissions from different fossil fuels, even if system-wide leakage of NG is considerably higher than previously estimated, the incremental emissions are unlikely to be large enough to negate the climate benefits associated with switching from coal to NG (Brandt et al. 2014). The recent literature asserting that system-wide emissions of NG are underestimated appears to focus on implications for electric power generation; none of these studies were found to compare impacts of NG vehicles to vehicles fueled by conventional petroleum.

[4] EPA defines a pneumatic device as an automated instrument used for maintaining a process condition such as liquid level, pressure, pressure difference, and temperature (EPA 2014).

[5] EPA publishes the Inventory of U.S. Greenhouse Gas Emissions and Sinks annually at http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Figure 6.2.2-2. U.S. Natural Gas Production by Source, Annual Energy Outlook 2014 Reference Case



Source: EIA 2014c.

6.2.2.2 Shale Gas and Hydraulic Fracturing

Shale gas deposits consist of hydrocarbons trapped in fractures and pores of rock deep underground. The hydrocarbon content per unit of rock volume is significantly less than in conventional hydrocarbon reservoirs. Low permeability of the source rock and low energy density of the gas fields are driving factors for the upstream environmental impacts of hydraulic fracturing compared to conventional NG extraction.

Impacts of hydraulic fracturing result from three primary activities: supporting infrastructure, the drilling and fracturing process, and handling waste from the extraction process (Entrekin et al. 2011). Due to similarities between shale gas and shale oil deposits, many impacts of shale gas extraction are similar to those of shale oil extraction.

The low energy density of shale gas fields relative to conventional gas fields necessitates the construction of greater amounts of infrastructure (well pads, parking for employees, gas processing and transport facilities, and roads) to extract the gas. The primary metrics for evaluating the impact of this additional infrastructure include land use change and emissions from construction and operation.

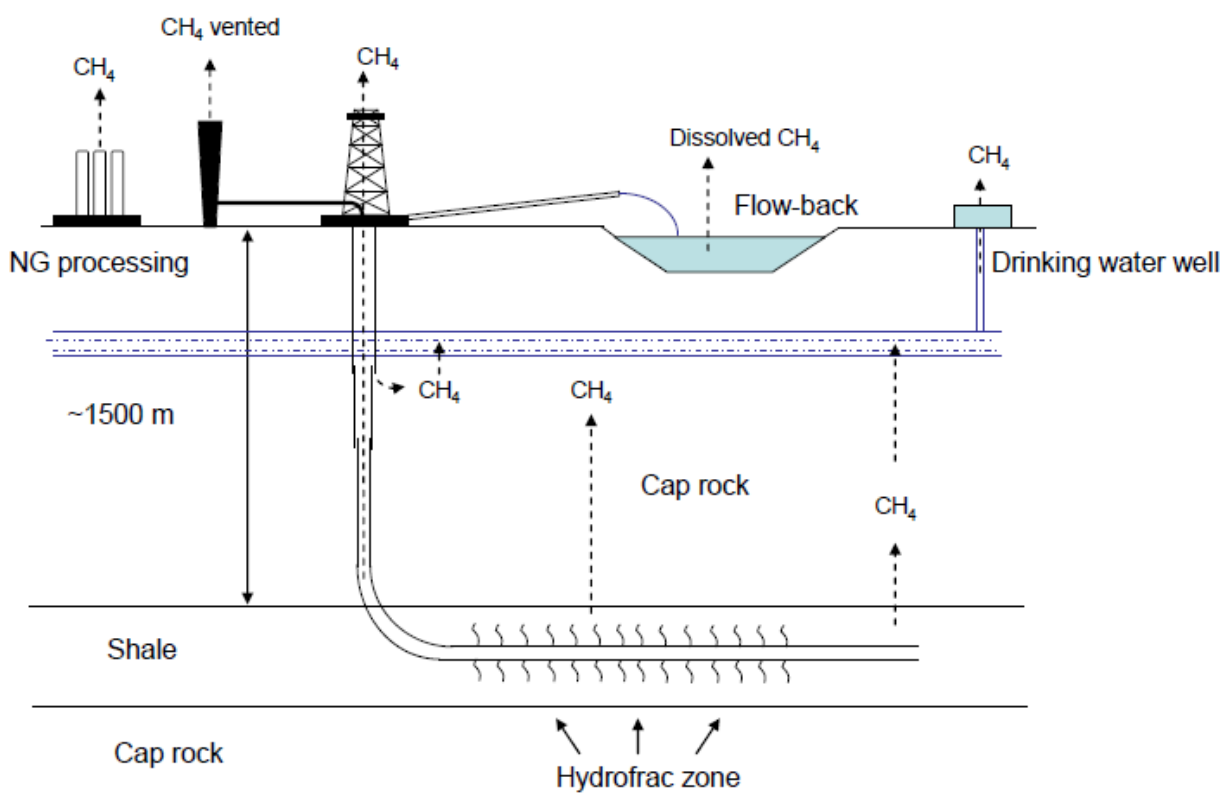
Although an individual well pad typically occupies only 1.5 to 3.0 hectares of land (Entrekin et al. 2011), the low energy density of shale gas necessitates a well placement density ranging from 1.15 to 6 wells per square kilometer. In contrast, a conventional U.S. NG field has a density of only 0.38 well per square kilometer (Lechtenböhmer et al. 2011). The well pad density depends on the porosity of the

underground shale and the relative shares of horizontal and vertical drilling operations. A representative multi-well pad size in the United States would occupy 16.2 to 20.2 hectares during operation and 4.0 to 12.2 hectares after partial restoration (Lechtenböhmer et al. 2011).

In addition to land use impacts, truck traffic to and from the wells generates both GHG emissions and criteria air pollutants, including particulate matter, sulfur dioxide, NO_x, non-methane volatile organic compounds, and carbon monoxide. Due to the greater numbers of wells and infrastructure, truck traffic servicing shale gas wells may be higher than for conventional gas wells, resulting in incremental emissions. The construction of roads and other infrastructure also increases runoff and sediment deposition in surface waters, negatively affecting ecosystems and increasing the risk of eutrophication (Entrekin et al. 2011).

In order to release NG from rock formations, a significant amount of energy must be used to fracture the rocks and bring the hydrocarbons to the surface, which releases CO_2 (and results in some CH_4 leakage, as described in Section 6.2.2.1). GHG emissions from fuel used for drilling can vary greatly depending upon the characteristics of the well being drilled. Some wells produce less gas and thus require more energy to bring it to the surface (Lechtenböhmer et al. 2011). In addition, higher CO_2 content in the extracted gas results in higher net emissions. Excluding CH_4 leakage, emissions for shale gas exploration, extraction, and processing are about 17.9 g of CO_2e per MJ of NG (Lechtenböhmer et al. 2011). A graphic depiction of CH_4 flows during hydraulic fracturing is shown in Figure 6.2.2-3. Drilling also uses large amounts of water, producing significant amounts of wastewater.

Figure 6.2.2-3. Methane (CH_4) Flows during Hydraulic Fracturing



Source: Lechtenböhmer et al. 2011.

In addition to CH_4 leakage into the atmosphere (discussed in Section 6.2.2.1), it is possible for CH_4 to enter groundwater via the fracking process. CH_4 emissions are difficult to measure because CH_4 has several routes of escape, including the "hydrofrac zone" in the shale formation, onsite aboveground wastewater pools, and through the drilling equipment. This waterborne CH_4 is a potential GHG source, because it can evaporate into the atmosphere when it reaches the surface. In some active gas extraction areas in the northeastern United States, CH_4 concentrations in drinking water wells ranged from 19.2 milligrams per liter to 64 milligrams per liter compared to background levels of 1.1 milligrams per liter (Lechtenböhmer et al. 2011). The extent to which CH_4 in groundwater is attributable to hydraulic fracturing compared to naturally occurring sources of CH_4 is uncertain.

Injecting fracturing fluid at high pressure into the shale and previously fractured "crack" rock formations creates a potential pathway for pollutants to enter groundwater at multiple stages of the drilling process. Fracturing fluid may contaminate the environment through surface-level spills, drill casing leaks, or leaks inside rock formations that have been fractured. In addition to a saline solution, fracturing fluids include undisclosed additives that serve to increase the efficiency of the fracturing process and encourage gas recovery by reducing friction and maintaining viscosity within the well. The composition of fracturing fluids varies, with over 2,500 hydro-fracking products containing over 750 different chemicals (Entrekin et al. 2011). Of the additives, ethylene glycol, diesel, formaldehyde, benzene, toluene, ethylbenzene, and xylene are all of concern to human health and the environment (U.S. House of Representatives Committee on Energy and Commerce 2011). Only 10 to 30 percent of fracture fluids are typically recovered from wells, with the balance remaining in the environment (Ziemkiewicz et al. 2013).

Operation of NG extraction and processing equipment during the fracturing process releases non-GHG air pollutants, including aromatic hydrocarbons such as benzene (Howarth 2011). Air emissions show significant variation by region, with benzene concentrations much higher in the Barnett shale area of Texas relative to concentrations measured in Pennsylvania's Marcellus shale formation (Howarth 2011). Furthermore, onsite equipment operation has also been shown to contribute to ground-level smog formation due to emissions of smog-forming compounds (Howarth 2011, Lechtenböhmer et al. 2011).

A single well consumes 1,500 to 45,000 cubic meters of water over its lifetime and often receives repeated injections of fracturing fluid (Lechtenböhmer et al. 2011). The waste handling phase of hydraulic fracturing can result in pollution from "flowback"—i.e., fluid returning to the surface after being injected into underground rock formations. Flowback contains not only fracking additives, but may contain high levels of heavy metals, total dissolved solids, and trace amounts of radioactive elements from the rocks (Entrekin et al. 2011). Options for managing flowback include injection into abandoned gas or oil wells (not available in all locations), surface storage followed by treatment, or reuse in other well completions (Howarth 2011, Ziemkiewicz et al. 2013).

Surface storage and treatment are of particular concern, because CH_4 and other pollutants may leak from surface storage pools and tanks and contaminate groundwater and the atmosphere. Furthermore, municipal sewage treatment plants may be inadequate to treat toxic constituents of flowback and may release pollutants such as barium, strontium, and bromides into surface waters (Volz et al. 2011). Industrial wastewater treatment facilities are often better equipped to handle these pollutants; despite this advantage, they are not prevalent in the treatment of wastewater produced from hydraulic fracturing (Entrekin et al. 2011).

6.2.3 Biofuels

Within the realm of biofuels, this literature synthesis focuses on ethanol and biodiesel. Classes 2b–6 gasoline-powered vehicles are candidates for ethanol blend fuels. All diesel-powered HD vehicles are potential candidates for biodiesel blends.

6.2.3.1 Biodiesel

When used as a fuel in on-road vehicles, biodiesel offers significant GHG emission advantages over conventional petroleum diesel. Biodiesel is a renewable fuel that can be manufactured domestically from used cooking and plant oils, as well as from animal fats, including beef tallow and pork lard. To produce biodiesel, oils and fats are put through a process called *transesterification*, which converts oils and fats by reacting them with a short-chain alcohol and catalyst to form fatty-acid methyl esters (NREL 2008). Biodiesel for sale in the United States must meet standards specified by American Society for Testing and Materials (ASTM) International. Biodiesel blends of 6 to 20 percent must meet ASTM D7467 specifications while "pure" biodiesel must meet ASTM D6751 specifications.

An EPA report on emissions from HD engines analyzed the results from 39 separate studies and found biodiesel use in on-road vehicles decreases tailpipe emissions of particulate matter, carbon monoxide, and hydrocarbons commensurately with blend level (EPA 2001). Although the report found a slight increase in NO_x, a 2006 analysis released by the National Renewable Energy Laboratory (NREL) found no significant increase in NO_x for biodiesel blends up to B20 (20 percent biodiesel, 80 percent petroleum diesel) (NREL 2006). A 2009 Society of Automotive Engineers report corroborated the results found in the NREL 2006 analysis and found that pure biodiesel (B100) increased NO_x emissions about 2 to 3 percent over conventional diesel emissions (Robbins et al. 2009). ANL's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool shows that replacing one single unit short-haul diesel truck with a comparable model running on B20 reduces GHG emissions by 5 tons annually. Reductions of other air pollutants, including carbon monoxide, NO_x, particulate matter, and volatile organic compounds, are comparable (ANL 2013a).

Well-to-wheels analyses completed by NREL and ANL show that GHG emissions can be decreased by up to 52 percent when using biodiesel as a replacement for petroleum diesel (AFDC 2014a). ANL's GREET model estimates well-to-wheels emissions for petroleum diesel and biodiesel at 387 g of CO_2 per mile (g CO_2/mi) and 93 g CO_2/mi, respectively (ANL 2013b). These well-to-wheels emissions assume a soybean feedstock, which has lower life-cycle CO_2 emissions than algae feedstocks.

Petroleum diesel and biodiesel blends up to 5 percent biodiesel are considered "pure" petroleum diesel. Any higher biodiesel concentrations must be documented on a sticker prominently displayed on the fuel pump, as required by federal law, because some engines are not warrantied for biodiesel concentrations above 5 percent. B20 and other lower concentration biodiesel blends can be used in nearly all diesel equipment with few or no engine modifications. B100 and other high level blends used in motors not approved by the manufacturer to use B100 can degrade and soften incompatible vehicle parts and equipment such as hoses and plastics. Starting in 1994, many engine manufacturers began replacing the vulnerable parts of the engine, including rubber components, with materials compatible with biodiesel blends. Because not all engines are compatible with higher level blends, NREL recommends contacting the engine manufacturer before using them (NREL 2008). Reducing the blend of biodiesel used in the winter months can avoid having biodiesel crystallize in cold temperatures. Biodiesel performance improves in cold temperatures as the blend is reduced.

6.2.3.2 Ethanol

Although the use of high ethanol content fuel such as E85 is generally limited in HD vehicles, ethanol used as an on-road vehicle fuel has the potential to substantially reduce GHG emissions compared with conventional gasoline emissions, depending on feedstock and blend level. Most ethanol produced in the United States is manufactured from corn and other starch-based crops. However, ethanol also can be produced from cellulosic feedstocks like woody biomass and crop residue. Similar to biodiesel, when ethanol crops are grown they capture CO_2 and offset the GHG emissions later released through fuel combustion. The higher the blend of ethanol in the fuel, the lower the net GHG emissions.

Depending on the energy source used during production, corn-based ethanol can reduce well-to-wheels GHG emissions by up to 52 percent compared to gasoline (Wang et al. 2007). Cellulosic ethanol can create an even larger reduction in GHG emissions (around 86 percent reduction) (AFDC 2014b). The GREET Model estimates well-to-wheels emissions for gasoline and pure corn ethanol to be 446 g CO_2/mi and 307 g CO_2/mi, respectively.

Most of the gasoline sold in the United States contains up to 10 percent ethanol (E10). All gasoline-powered vehicles are approved by EPA to use E10 in their engines because the fuel is considered "substantially similar" to gasoline. Regarding other low-level blends of ethanol, 15 percent ethanol and 85 percent gasoline (E15) was recently approved by EPA for use in conventional gasoline passenger vehicles of model year 2001 and newer. However, these blends generally are not suitable for most conventional HD engines (AFDC 2014c). Besides E10, the most commonly used blend of ethanol in the United States is a blend of gasoline and ethanol containing 51 to 83 percent ethanol (E85). Ethanol blends over E15, including E85, should only be used in flexible fuel vehicles (FFVs), because ethanol has a high alcohol content and can soften and degrade gaskets, seals, and other equipment in non-FFVs (DOE 2013b).

6.2.3.3 Indirect Land Use Change

Indirect land use changes occur when landowners make planting and harvesting decisions in response to market forces driven by biodiesel and ethanol production. As ethanol and biodiesel production increase, demand for feedstock crops increase and prices rise, thereby incentivizing landowners of grasslands and forest land to convert their acreage to grow crops instead. However, there is some controversy over whether increases in feedstock cause an increase in finished food product prices (e.g., corn, soybeans). A Congressional Budget Office (CBO) report estimates that ethanol production only contributed to between 0.5 and 0.8 percentage points of the 5.1 percent increase in food prices that occurred between April 2007 and April 2008 (CBO 2009). The amount of carbon stored per acre of cropland, including in soil, is generally less than that of forest or native grassland. There are widely differing viewpoints on the extent to which CO_2 emissions from indirect land use changes offset the emissions reductions associated with substituting biofuels for petroleum-based fuels. For example, a study by Searchinger et al. (2008) found that biofuels production in the United States using corn or switchgrass feedstocks will increase agricultural commodity prices, leading to extensive land-use changes and large net increases in GHG emissions. By comparison, a response by the U.S. Department of Energy (DOE) disputed many of the assumptions in Searchinger et al. (2008), with DOE suggesting that "it is reasonable to expect that rigorous, peer-reviewed, science-based land use models will show that indirect land use change impacts of biofuels production are far smaller" (DOE 2008). Experts differ on their opinions of the strength of the price signal in influencing landowners' decisions to convert to biofuel production; opinions also differ regarding the magnitude of change in carbon storage for land planted in biofuel crops versus land in its prior condition.

6.3 Materials and Technologies

This section reviews LCA literature related to six broad categories of materials and technologies that can improve HD vehicle fuel efficiency. Section 6.3.1 discusses manufacturing technologies that can reduce vehicle mass and weight. Section 6.3.2 reviews LCA impacts associated with mass reduction by material substitution. Sections 6.3.3 and 6.3.4 examine technologies related to tires and vehicle aerodynamics, respectively. Section 6.3.5 discusses trailers, and Section 6.3.6 examines hybrid vehicles and batteries. As noted in Section 6.1.1, for some of the studies considered in this chapter, the authors used existing models such as the GREET model to assess life-cycle emissions. While GREET has a module for upstream manufacturing energy and emissions for passenger cars and light-duty trucks, a heavy-duty truck (HDV) module was still under development at the time this analysis was conducted. Other studies included independent assessments of life-cycle implications using study-specific models developed from life-cycle inventory data sources.

6.3.1 Vehicle Mass Reduction by Manufacturing Technologies

Manufacturing technologies discussed in this section improve fuel efficiency by reducing vehicle weight. Certain manufacturing technologies can also reduce waste generated and provide energy savings from streamlined manufacturing that can further reduce the environmental impacts from across the vehicle life cycle.

6.3.1.1 Laser Welding

Standard arc welding techniques use an electrical arc to melt the work materials as well as filler material for welding joints, whereas laser welding joins pieces of metal with a laser beam that provides a concentrated heat source. One study of laser welding in production processes found improved and more efficient vehicle manufacturing and reduced material use for the same level of energy consumption (Kaierle et al. 2011).

6.3.1.2 Hydroforming

Hydroforming is the process of creating hollow metal structural parts from a tubular element that is shaped inside a mold by fluid under pressure, resulting in a reduced number of moldings required and lighter parts. The process allows manufacturers to produce entire components in a single process that would otherwise be made using multiple parts joined together. For example, a General Motors plant in Germany employed hydroforming technology and achieved a 20 percent reduction in the number of welding operations required (Galitsky 2008 citing GM 2001). Hydroforming has been applied to steel and aluminum automobile parts to reduce vehicle weight. Hydroforming has led to mass savings by eliminating the flanges required for welding and allowing for the use of thinner steel (Kocańda and Sadłowska 2008).[6] The use of hydroforming to manufacture a hollow crankshaft reduced material usage by 87 percent and resulted in a 57 percent weight reduction when compared to a solid shaft with the same torque formed from conventional welding techniques (Shan et al. 2012).

[6] Kocańda and Sadłowska (2008) did not perform an LCA of hydroforming but instead discussed the mass savings achieved from the production technology.

6.3.1.3 Tailor-welded Blanks

Tailor-welded blanks are an emerging weight-saving technology in vehicle manufacturing, in which two or more sheet pieces with different shapes, gages, and material specifications are welded together so that the ensuing sub-assembly is lighter and has few components (Rooks 2001). The use of tailored blanks eliminates the need for additional reinforcements and overlapping joints in a vehicle body, and it saves materials, further reducing the weight.

6.3.1.4 Three-dimensional Printing

Other opportunities for weight reduction in HD trucks may come from secondary mass reduction, whereby the size (and mass) of components is partially determined by the need to bear the mass of other components (Alonso et al. 2012). Therefore, if a vehicle's mass is reduced, the mass of some components can also decrease. This approach is applicable to both steel and aluminum parts.

Three-dimensional (3D) printing, also known as "additive manufacturing," is a collection of technologies capable of fusing materials to manufacture complex composite components in a single process step (Baumers et al. 2011). Because this technology allows the manufacturer to print the desired product and minimal support structures, 3D printing is expected to reduce the amount of materials used, wastes and recyclables generated, and the energy required to manufacture a product. Additive manufacturing on average uses 50 percent less energy and saves up to 90 percent on material costs compared to traditional manufacturing (Werrell and Femia 2012).

3D printing in vehicle manufacturing has been mostly limited to prototyping of components as a design and engineering tool, and has been used to make small parts for visual analysis, but has otherwise been seldom used to produce final production parts in vehicles (Richardson and Haylock 2012). Because additive manufacturing is a new and evolving technology, peer reviewed studies have been limited on the topic and focus their scope only on the creation of small parts in the manufacturing process. As the technology continues to evolve and penetrates the manufacturing sector, additional research and targeted studies should provide better insight into potential energy savings.

6.3.2 Vehicle Mass Reduction by Material Substitution

Reducing vehicle mass through material substitution has implications across the life cycle of a vehicle, including reducing the amount of conventional material required to manufacture vehicles; increasing the amount of alternative, lighter-weight materials used to manufacture vehicles; saving fuel over the life of the vehicle; and influencing disassembly and recycling at end of life. Replacing materials such as conventional steel with other lightweight material reduces vehicle fuel consumption but also could increase the upstream environmental burden associated with producing these materials. This section focuses on three primary material categories: aluminum and high-strength steel, polymer composites, and magnesium and titanium.

6.3.2.1 Aluminum and High-Strength Steel

Aluminum, which is used intensively in the transportation sector, combines a high strength-to-weight ratio, corrosion resistance, and processability, and can be used as a substitute for heavier conventional steel (Cheah et al. 2009). High-strength steel has the same density as conventional steel, but provides greater strength, so less high-strength steel is required to fulfill the same function as conventional steel. Aluminum and high-strength steel can reduce weight while providing strength and rigidity similar to conventional steel. Aluminum is lighter than the conventional steel it replaces, and high-strength steel saves weight by using less material to provide the same level of strength. Aluminum is a suitable

substitute for cast-iron components, molded steel parts such as wheels, and stamped-steel body panels, while high-strength steel provides the greatest weight-reduction benefits in structural or load-bearing applications, rather than non-load-bearing uses, where strength is less of a factor in material selection (Cheah and Heywood 2011, Kim et al. 2010b, Koffler and Provo 2012, Mohapatra and Das 2014).

Two studies in the literature synthesis focus on LCA impacts of substituting aluminum for conventional steel components in HD vehicles.[7] One study determined that increased energy use and GHG emissions associated with producing HD truck aluminum wheels substituted for conventional steel wheels were offset by use-stage savings after 224,000 miles of travel (Koffler and Provo 2012). A separate study found that a 13.4 percent reduction in MD truck mass through material substitution with aluminum decreased life-cycle energy consumption by 209.3 gigajoules compared to a baseline vehicle using comparable steel components, and a 3.2 percent mass reduction in HD bus mass through material substitution with aluminum reduced life-cycle energy consumption by 484.3 gigajoules (Song et al. 2009).[8]

Many studies emphasize the sensitivity of LCA results to the amount of recycled material used in vehicle components and the materials recycling rate at end of life. One study suggested that aluminum supplies will likely be easier to access in the future through secondary sources (i.e., recycling aluminum through "landfill mining" or "urban mining") than through primary aluminum (i.e., from bauxite mining) (Chen and Graedel 2012b). This suggests that the quality of secondary aluminum will impact the cost and supply of aluminum used in vehicles in the future. Aluminum alloy scrap accumulates alloy elements, resulting in loss of quality when recycled. Avoiding quality loss will require identifying and segregating alloys at the point of discard so that the alloy can be reused as originally designed (Chen and Graedel 2012a). The region where an aluminum smelter is located also adds variation to GHG emissions because aluminum's carbon intensity is strongly tied to the electricity grid's carbon intensity in the smelter's region, with a 479 percent difference in emission factors depending on how the electricity is generated (Colett 2013).

Many other studies examine life-cycle impacts of substituting aluminum and/or high-strength steel in light-duty vehicles, or vehicles in general, with some studies focusing on material substitution in specific vehicle components and other studies estimating overall mass reduction from material substitution and vehicle redesign (Bandivadekar et al. 2008, Bertram et al. 2009, Birat et al. 2003, Cáceres 2009, Das 2014, Dubreuil et al. 2010, Geyer 2008, Hakamada et al. 2007, Kim and Wallington 2013, Kim et al. 2010a, Lewis et al. 2014, Lloyd and Lave 2003, Mayyas et al. 2012, Stodolsky et al. 1995, Ungureanu et al. 2007, Weiss et al. 2000). A detailed discussion of studies related to light-duty vehicles was presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS.

Both the HD and light-duty vehicle literature support the following findings from the MY 2017–2025 CAFE standards Final EIS:

[7] The following studies indicated that they relied—at least partially—on industry funding or industry-funded data to evaluate the life-cycle impacts of aluminum and high-strength steel material substitution: Koffler and Provo (2012), Kim and Wallington (2013), Kim et al. (2010a), Geyer (2007, 2008), Dubreuil (2010), and Birat et al. (2003). All of the studies reviewed have undergone peer review for publication in academic journals, with the exception of Koffler and Provo (2012), which underwent a critical review but has not been published in an academic journal. Certain studies noted where critical reviews were conducted in accordance with ISO 14044 standards on either the methodology (Geyer 2008), life-cycle inventory inputs (Dubreuil 2010), or both (Koffler and Provo 2012), or where critical review was not performed (Bertram et al. 2009).

[8] The authors chose to evaluate an Isuzu N-series medium-duty truck with a total curb weight of 3,600 kilograms and a Provost Car XLII bus with a total weight of 16,980 kilograms. Both vehicles are a subset of HD vehicles as defined in this EIS.

- In general, across the entire vehicle life cycle, reductions in energy use and GHG emissions during the use stage of vehicles due to aluminum and high-strength steel material substitution exceed the increased energy use and GHG emissions needed to manufacture these lightweight materials at the vehicle production stage.
- The magnitudes of life-cycle GHG-emission reductions and energy-use savings are influenced by the amount of recycled material used in vehicle components, the end-of-life material recycling rate, the lifetime of vehicles in use, and the location of aluminum production.

6.3.2.2 Polymer Composites

Glass- and carbon-fiber-reinforced polymer composites, including bio-based and nanocomposites, offer high strength-to-weight ratios, thermal and flame resistance, enhanced barriers that reduce or eliminate gas permeation, and corrosion resistance (Khanna and Bakshi 2009). Song et al. 2009 found significant use phase energy savings from substituting composite components for steel in a medium-duty truck and a bus, with use phase energy savings from composites over 2.5 times better for the bus than the truck due to the longer useful life and distance traveled for buses.

Most of the LCA literature on composites examines applications in light-duty vehicles (Boland et al. 2014, Cheah 2010, Das 2011, Gibson 2000, Lloyd and Lave 2003, Keoleian and Kar 1999, Khanna and Bakshi 2009, Overly et al. 2002, Tempelman 2011, Weiss et al. 2000). The detailed discussion of studies related to light-duty vehicles was presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS and supported the following findings that are also likely to be applicable to HD vehicle composite applications:

- Polymer composites (including those reinforced with glass, carbon fiber, or nanoclays) used in vehicle body panels are generally more energy- and GHG-intensive to produce compared to conventional steel, but greater or less than aluminum depending on the study. However, energy-efficient manufacturing processes, such as the pultrusion, injection molding, and thermoforming processes, can make fiber-reinforced composites less energy intensive to produce relative to both steel and aluminum.
- Carbon-fiber-reinforced polymer composites used for specific automotive parts (e.g., a floor pan) are typically less GHG-intensive across the life cycle (including end of life) than similar components made from conventional materials, but the magnitude of the difference depends on the vehicle weight reduction due to the composite materials.
- The use of polymer composites in vehicle body panels and air intake manifolds leads to reduced energy use and GHGs emitted over the vehicle life cycle compared to vehicles with similar aluminum or steel parts. This reduction is due to significant reductions in vehicle weight and associated improvements in fuel economy.
- For other environmental impact categories (e.g., acidification, water use, water quality, landfill space), polymer composite materials also tend to result in overall lower life-cycle impacts compared to conventional steel and to aluminum.
- Composites are more difficult to recycle than their metal counterparts. Some studies assign a credit for incineration of composites in a waste-to-energy plant, but this could overstate composites' life-cycle benefits compared to metals if this energy-recovery option is unavailable. In general, end-of-life assumptions and the post-consumer material content of composite materials have not been studied as thoroughly as other life-cycle phases.

6.3.2.3 Magnesium and Titanium

Magnesium is a very lightweight metal that is already used in a limited way for mass reduction in vehicles—current on-road vehicles use approximately 11 pounds per vehicle, on average (Cheah 2010). Magnesium is more expensive and energy-intensive to produce than the steel it typically replaces, but it offers significant fuel economy improvements due to a 60 percent weight reduction. Titanium is denser than magnesium, but it provides the highest strength-to-weight ratio of all metals. It can also offer significant fuel economy savings, but it is costly. Depending on the alloy used, both magnesium and titanium offer comparable strength and durability performance relative to more commonly used materials such as steel but at a lower density.

Manufacturing magnesium into automotive components presents an additional environmental burden over manufacturing steel, with an energy demand that ranges from 8 to 10 times that of conventional steel manufacturing (Cheah 2010). Magnesium components have been determined to have 2.25 times the impact on human toxicity as steel (including respiratory effects, ionizing radiation, and ozone layer depletion) (Witik et al. 2011). A study by Witik et al. (2011) found that human toxicity impacts of the magnesium material and manufacturing phase outweigh avoided impacts during the use phase relative to steel. End-of-life recovery of magnesium is fairly common, with recovery rates in excess of 90 percent (Ehrenberger 2013), comparing favorably with recovery rates for steel and aluminum. The energy associated with magnesium recycling is very small compared to the energy used to manufacture automotive components from virgin magnesium. The emissions solely from magnesium recovery during vehicle disposal are 1.1 kg CO_2e per kg of magnesium (Ehrenberger 2013). Because this value is much lower than that of virgin magnesium—typically about 20 to 47 kg CO_2e per kg of magnesium—incorporating recycled magnesium in vehicles can yield significant energy savings.

Compared to literature regarding magnesium, the literature characterizing the life-cycle impacts of titanium components in vehicles is more limited, with little recent research available on the subject. Gibson (2000) found that the energy and emissions associated with titanium manufacture were the highest of the light-weighting techniques studied. Although titanium has a higher mass-to-strength ratio than magnesium, it offers less direct mass savings over steel because it is heavier than magnesium (disregarding uses in specialized, load-bearing components).

The current literature review did not locate studies examining the life-cycle impacts of magnesium and titanium substitution in HD vehicles. However, the detailed discussion of studies related to light-duty vehicles presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS supported the following findings that are also likely to be applicable to magnesium and titanium substitution in HD vehicles:

- Magnesium and titanium are more energy- and GHG-intensive to produce than steel or aluminum.
- Significant reductions in vehicle weight and GHG emissions can be achieved by substituting magnesium and titanium for heavier components, but break-even distances (at which fuel economy savings outweigh increased production energy) can be relatively high in relation to other materials. Break-even distance declines with higher proportions of recycled magnesium.

6.3.3 Tires

Tires impact vehicle fuel economy through rolling resistance, defined as “the energy consumed by a tire per unit of distance traveled” (Mammetti et al. 2013). The vehicle’s engine converts the chemical energy in the fuel into mechanical energy, which is transmitted through the drivetrain to turn the wheels. Rolling resistance is a force at the wheel axle in the direction of travel required to make a loaded tire roll. As a result, the engine must consume additional fuel to overcome the rolling resistance

of the tires when propelling the vehicle (NAS, 2006). For a Class 8 tractor-trailer, this resistance accounts for 13 percent of energy used at a highway speed of 65 miles per hour (TIAX 2009). Changes to the physical design of tires can reduce the energy needed to overcome rolling resistance, leading to reductions in fuel consumption. For example, rolling resistance can be reduced through the use of low rolling resistance (LRR) tires and wide-base single (WBS) tires, which are wide tires that replace dual tire sets, and through implementation of tire pressure systems to keep tires at a higher pressure. LRR and WBS tires may already make up half the tractor-trailer market (Sharpe and Roeth 2014).

A study by Surcel and Michaelsen (2010) examined the influence of installing WBS tires on the drive axles alone, as well as drive axles and semi-trailer axles together. During several short-term tests, the WBS test tires resulted in fuel savings of 9.2 to 9.7 percent when compared to the control dual tires when placed on both drive and trailer axles. When placed on just the drive axles, the fuel savings were more modest, ranging from 0.8 to 5.1 percent, depending on the WBS tire model used. The authors also conducted long-term tests of two vehicles with dual tires driven over 100,000 kilometers during a 5-month period, followed by WBS tires installed on one vehicle while the other continued to use dual tires. Both vehicles then traveled over 175,000 kilometers during a 10-month period that showed an average reduction in fuel consumption of 5.11 percent for the truck with WBS tires, leading to an estimated net reduction in annual fuel consumption of 7,947 liters.

Surcel and Michaelsen (2010) also conducted short-term fuel consumption tests that replaced drive axle tires with LRR tires, which resulted in modest fuel savings of 1.4 to 2.4 percent, depending on the tire model used. In long-term tests, tandem axle trailers equipped with side skirts and LRR tires that traveled over 84,000 kilometers during a 7-month period showed an average reduction in fuel consumption of 6.27 percent compared to a control vehicle, leading to an estimated net reduction in annual fuel consumption of 1,574 liters.

A study by Mammetti et al. (2013) substituted a “normal” HD vehicle tire with a LRR tire through variations in tread pattern and rubber compound and found that a rolling resistance reduction of 0.45 kilograms per metric ton (kg/T) of vehicle mass resulted in a fuel consumption reduction of 1.15 liters per 100 kilometers, or 0.49 gallons per 100 miles. This equates to a fuel reduction of approximately 1.09 gallons per 100 miles for each kg/T reduction in rolling resistance.

A study by Bachman et al. (2005) examined the impact on fuel economy and NO_x emissions resulting from use of WBS tires on Class 8 tractor-trailers in a track test simulation of real world operating conditions. Across the testing conditions, use of WBS tires resulted in fuel economy improvements of 6.04 to 12.6 percent, when measuring fuel economy in miles per gallon. The results also showed reductions in NO_x emissions of 13.9 to 36.9 percent when measuring emissions in grams per distance traveled.

LaClair and Truemner (2005) used software to model the effect of tire rolling resistance on HD vehicle fuel consumption. Assuming a baseline average rolling resistance coefficient of 6.22 kg/T, the authors examined the effects of rolling resistance reductions. The study found fuel savings of 1.40 and 1.62 liters per 100 kilometers (0.60 and 0.69 gallons per 100 miles) for each kg/T reduction in rolling resistance for secondary road driving and highway road driving, respectively.

In addition to LRR and WBS tires, rolling resistance can be reduced through the use of tire pressure systems, which monitor low pressure and automatically inflate tires to reduce the energy loss incurred from under-inflated tires. This intervention can result in a fuel consumption reduction of about 1 percent (Sharpe and Roeth 2014, TIAX 2009).

The studies discussed above show fuel use and emission reductions from tire substitution during the use of HD vehicles, but the literature review did not identify HD vehicle LCA studies that examined impacts from other stages of the tire life cycle, including manufacturing, retreading, and end-of-life management specific to LRR and WBS tires. For light-duty vehicles, NHTSA (2009) found no significant relationship between rolling resistance and traction except for "wet slide" performance, where there was a strong and significant relationship between lower rolling resistance and poorer performance in wet slide conditions. The authors note that this correlation may be especially important to vehicles without anti-lock braking systems (ABS) because the wet slide coefficient relates most closely to locked-wheel emergency stops. NHTSA also subjected five tire models to on-vehicle tread wear testing and found no clear relationship between tread wear and rolling resistance levels. For six tire models subjected to significant wear during indoor tests (i.e., in a laboratory setting when not attached to a vehicle) the results did show a trend towards faster wear for tires with lower rolling resistance. It is unclear to what extent these light-duty results would apply to tires on HD vehicles.

Other anecdotal and qualitative sources indicate that production and use of tires designed to reduce rolling resistance may have impacts on tire manufacturing energy, durability, and opportunities for retread. A report from the North American Council for Freight Efficiency (NACFE 2010), based on data obtained from HD vehicle fleets in North America, noted that WBS tires could have effects on life-cycle impacts of tires compared to normal dual tires, such as weight reductions, increased brake life, and some difficulties with retreading. A reduction in durability and retread opportunities could decrease the effective life of the tires, creating more waste and requiring additional tire manufacturing. A paper prepared by the American Trucking Associations noted that WBS tires offer advantages in weight and fuel savings and increased brake life. However, WBS tires could also lead to a 25 to 35 percent reduction in miles to removal and higher failure following retread (Routhier 2007). A presentation from Michelin indicates that manufacturing a WBS tire could require 15 gallons of oil compared to 24 gallons required for manufacturing two dual tires (Johnston, undated). The information currently available suggests that LRR and WBS tire production could lead to both reductions and increases in environmental impacts relative to conventional dual tires. Further research is needed to better quantify environmental impacts of LRR and WBS tires across the entire life cycle. NHTSA welcomes comments about or citations to additional studies addressing these issues.

6.3.4 Aerodynamics and Drag

About two-thirds of the fuel used to propel trucks is consumed due to aerodynamic drag from trucks at highway speeds (ATDynamics 2014a). As the vehicle moves, drag originates in four major sections: the front, the gap between the trailer and the tractor, the undercarriage, and the rear. The rear sections alone account for approximately 75 percent of the total drag (ATDynamics 2014a). Trucking fleet tractors and trailers can be equipped with efficiency technologies that can reduce drag. While these technologies increase the gross weight of vehicles and trailers, several studies show that fuel efficiency savings from the reductions in aerodynamic drag are greater than the additional fuel needed to transport the additional weight, thus reducing net fuel consumption.

Aerodynamic technologies for tractors and trailers include gap reducers, side skirts, boat tails, end fairings, and advanced trailer skirts. All of these technologies, often called "fairings," reduce turbulence and improve fuel efficiency. A CEM (2009) study showed cab roof fairings achieved 6 to 8 percent fuel savings, adjustable cab roof deflectors achieved 2 to 4 percent savings, trailer side skirts achieved 4 to 7 percent savings, and trailer rear fairings achieved at least 1 percent savings in fuel consumption (CEM 2009). Another study found that the use of fairings, often in combination, can reduce fuel consumption by 6.4 percent, resulting in a reduction of about 0.925 metric tons CO_2 per truck on a monthly basis (Galipeau-Belair et al. 2013).

A variety of materials are used for aerodynamic technologies, as summarized in Table 6.3.4-1. For each technology type, the reported materials used, fuel savings, and additional weight are listed.

Table 6.3.4-1. Summary of Currently-Available Aerodynamic Technologies

Aerodynamic Technology	Company	Materials Used	Weight Added (lbs.)	Manufacturers' Claimed Fuel Savings (%)
Trailer Gap Reducers	Freight Wing	Thermoplastic PolyOlefin (TPO)	55	2
Trailer Boat Tails	Aerodynamic Trailer Systems	Polymer Skins, Steel Bolts and Aluminum Rails	130	4–7
	Slipstreem Aerodynamics		150	3–4
	ATDynamics	Thermoplastic Composite, Galvanized Steel	115-165	5.1–5.5
	SmartTruck Systems			5.5–10.5
Trailer Side Skirts (full vehicle kit)	Aero Tech Fleet Products	Thermoplastic PolyOlefin (TPO)	190	7
	Fleet Engineers	Aluminum	199	6
	Freight Wing	Polypropylene thermoplastic	170	7.45
	Edge Skirts	Thermoplastic composite	106-170	7.3
	Silver Eagle	Aluminum and Steel	390	5.7
	SA Concepts	Aluminum and Rubber Impact Guard	180	4
	ATDynamics	Thermoplastic Composite, Stainless Steel	105-175	4–7
	Wabash Composites	HDPE and Steel	256	5–6
	Ridge Corporation	Patented high impact material	200	5.2–7.2
	Strehl	Steel Composite with polyethylene core TPV Rubber	223	7

Notes:

Manufacturer's claimed fuel savings are based on values reported by manufacturers for each combination of aerodynamic technology and material used. These claimed fuel savings are not normalized to a common baseline, drive-cycle, or vehicle. These claimed fuel savings were not independently verified by NHTSA. This table is not intended to serve as a comprehensive list of available aerodynamic technologies and does not serve as an endorsement of any technology, product, or company. The United States Government does not endorse products or manufacturers.

Sources: Aero Tech 2014, ATDynamics 2014b, ATDynamics 2014c, ATS 2014, EcoVet Furniture 2014, Edge Skirts 2014, Fleet Engineers 2014, Freight Wing 2014a, Freight Wing 2014b, Ridge Corporation 2014, SA Concepts 2014, Silver Eagle 2014, Slipstreem 2014, Strehl 2014, Wabash 2014.

A recent study by DOE's Vehicle Technologies Office notes that a full truck and trailer aerodynamic package can weigh up to 4,000 pounds (DOE 2013c). The additional cumulative weight of adding one or more pieces of aerodynamic technology to a HD vehicle could impact the overall cargo capacity and freight efficiency when calculated on a delivered ton-mile per gallon basis. Therefore, mass-reduction technologies, as described in Section 6.3.1 and Section 6.3.2, can help maximize fuel efficiency while minimizing or eliminating the additional weight and subsequent impacts on freight efficiency (DOE

2013c). Additional research is needed on this topic to determine the life-cycle impacts of applying aerodynamic technologies with respect to freight efficiency and mass-reduction technologies. NHTSA welcomes comments about or citations to additional studies addressing these issues.

The studies discussed above indicate that fuel savings resulting from aerodynamic technologies exceed the additional fuel demand resulting from the added weight of aerodynamic materials during vehicle use. Additional life-cycle impacts are associated with the manufacturing, transport, and disposal of aerodynamic technologies, but this literature review did not locate any studies that specifically assessed impacts from manufacturing, transport, and disposal of aerodynamic technology. Further research is needed on this topic, but many of the materials commonly used for aerodynamic technologies are also used for vehicle mass reduction, discussed in Section 6.3.2. NHTSA welcomes comments about or citations to additional studies addressing these issues.

Most of the available scientific literature is focused on technologies for reductions in aerodynamic drag for trucking fleet tractors and trailers. However, technologies may allow for fuel economy improvements in other HD vehicle segments, including Classes 2b–3 vehicles and vocational vehicles. NHTSA does not assume that vocational vehicles will require aerodynamic improvements to comply with the new standards. However, NAS (2010) reported the possible aerodynamic improvements for vocational vehicles could yield 0.5 to 3 percent improvements in fuel economy, depending on the aerodynamic device and the duty-cycle average speed. A full aerodynamics package offered a 1.5 percent improvement in fuel economy for a straight box truck operating at an average speed of 30 mph.

6.3.5 Trailers

Tractor-trailers are the largest consumers of fuel within the HD vehicle sector and therefore offer significant opportunity for reductions in environmental impacts through efficiency improvements (Façanha et al. 2012). With the exception of refrigeration systems, vehicle trailers do not themselves consume energy or generate GHG emissions during use, but improvements in trailer design can affect the overall efficiency of freight transit by reducing fuel consumption associated with the ton-miles of freight hauled. Trailers can contribute as much as 34 percent to the total drag of a tractor-trailer (Sharpe and Roeth 2014). In response to rising fuel costs, lower adoption costs, and environmental regulations (including both EPA's SmartWay Transport Partnership and California Air Resources Board's Tractor-Trailer Greenhouse Gas regulation), vehicle trailer technologies have been widely adopted in the past decade by medium- and large-scale shipping fleets and will continue to be adopted by increasing numbers of operators within the timeline of this EIS.

Trailer refrigeration systems, used to provide trailer cooling for transport of fresh and frozen foods, are typically powered by small diesel engines. Research has suggested that trailer refrigeration systems powered by electricity could decrease the life-cycle environmental impacts from refrigerated trailers. A demonstration project by Shurepower, LLC for the New York State Energy Research and Development Authority and the EPA SmartWay Transport Partnership evaluated the environmental benefits of switching from a trailer refrigeration unit (TRU) powered by diesel fuel to a hybrid diesel-electric trailer refrigeration unit (eTRU) partly powered by grid-supplied electricity. The results of the analysis show that the switch from conventional diesel TRUs to eTRUs resulted in net emissions reductions of 6.982 grams per kilowatt-hour (g/kWh) of NO_x, 0.522 g/kWh of particulate matter up to 10 micrometers in size (PM10), and 5.427 g/kWh of CO. The hybrid diesel-electric TRUs consumed 15.75 percent less diesel fuel than trucks equipped with conventional diesel-powered TRUs, offering corresponding decreases in GHG emissions (Shurepower 2007).

Many design considerations for efficient trailers are based on efficiency principles for vehicle technology discussed in other sections this chapter, including aerodynamics, mass reduction, and tire technologies. The current literature review did not locate data on the life-cycle environmental impacts from measures and technologies specifically designed to reduce the weight of trailers (e.g., studies quantifying the manufacturing, use, and end-of-life environmental impacts of vehicle trailer components), but it is likely that materials and technologies used for trailers will include the aerodynamics, mass reduction, and tire technologies discussed above. Further research is needed on this topic; NHTSA welcomes comments about or citations to additional studies addressing these issues.

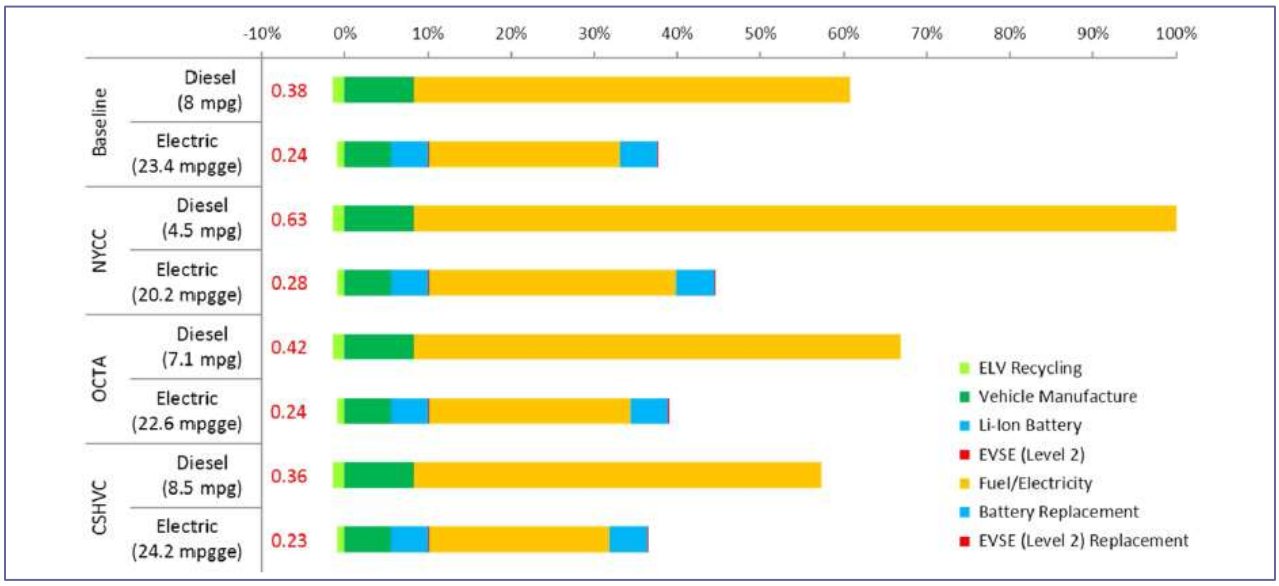
6.3.6 Hybrid Vehicles and Batteries

Electric vehicles (EVs) use battery technologies to provide power, thereby reducing or even eliminating liquid fuel consumption during vehicle operation. EVs cover a range of different engine types, including battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) (Notter et al. 2010, Patterson et al. 2011, DOE 2013a). BEVs are purely electrically powered and do not incorporate an internal combustion engine. HEVs incorporate a battery and electric motor combined with an internal combustion engine (or fuel cell), and have on-board charging capabilities (e.g., regenerative braking). PHEVs are fitted with a large capacity rechargeable battery that can be charged from the electric grid; like HEVs, they also use an internal combustion engine or fuel cell as backup when battery power is depleted.

An accounting of the life-cycle environmental impacts of BEVs and PHEVs includes upstream impacts from generating electricity, which depends on the efficiency of power plants and the mix of fuel sources used, also referred to as the "grid mix." Chapter 6 of the MY 2017–2025 CAFE standards Final EIS presented an extensive discussion of this issue. Grid electricity is not expected to account for a significant share of fuel use in HD vehicles, but HEVs are likely to be used in an increasing share of Classes 2b–6 pickups, vans, and vocational vehicles. Therefore, the LCA literature review in this section focuses on materials and technologies associated with HEVs (many of which are also applied in BEVs and PHEVs).

Although BEVs and PHEVs are not expected to account for a significant share of HD vehicles, it should be noted that there are viable options for full electrification for urban delivery vehicles of gross vehicle weight (GVW) Classes 4−6 (6,350−11,800 kg, or 14,001−26,000 lbs.) (Fenga and Figliozzia 2012). The relative benefits of electric trucks depend heavily on vehicle efficiency associated with drive cycle, diesel fuel price, travel demand, electric drive battery replacement and price, electricity generation and transmission efficiency, electric truck recharging infrastructure, and purchase price. For a drive cycle with frequent stops and low average speeds in urban settings, electric trucks emit 42 to 61 percent fewer GHG emissions and consume 32 to 54 percent less energy than diesel GVW Classes 4–6 trucks, depending upon vehicle efficiency cases (Lee et al. 2013). Studies demonstrate that over a range of driving conditions electric trucks have lower emissions than conventional diesel engines, as shown in Figure 6.3.6-1. The ranges of GHG emissions provided in Lee et al. (2013) reflect differences in the mix of fuels used to generate grid electricity used in electric trucks; the comparisons with diesel GVW Classes 4–6 trucks cover the full life cycle (i.e., they include upstream and downstream emissions).

Figure 6.3.6-1. HD Vehicle Life-Cycle Emissions Comparisons between Conventional Diesel and Electric Power for Delivery Trucks in Gross Vehicle Weight Class 5 (16,001–19,500 lbs.)



Notes: Comparative scenarios are for cities with varying representative driving cycles. NYCC is for dense urban driving, similar to New York City; OCTA is for a bus route with medium distances between stops, similar to transit in Orange County; And CSHVC is for a delivery truck in a combination of suburban and urban settings.
mpg = miles per gallon; mpgge = miles per gallon gasoline equivalent; NYCC = New York City Cycle; OCTA = Orange County Transit Authority Bus Cycle; CSHVC = City-Suburban Heavy Vehicle Cycle; ELV = End-of-Life Vehicle; EVSE = Electric Vehicle Supply Equipment [e.g., charging station]
Source: Lee et al. 2013.

HEV drive trains for GVW Classes 4–6 trucks can achieve fuel savings of up to 17 percent, and can be financially attractive for HD vehicle operators. One study also reports that maintenance requirements associated with hybrid-diesel are significantly better than conventional diesel (Eick 2012). A special application in HD trucks is freight delivery to and from marine ports, which requires very low speed driving in the port area, where HEVs can operate in the electric mode at low speed and with the engine off at idle (Zhao et al. 2013). Ports are ideal locations to reduce HD vehicle emissions with HEVs because truck freight traffic can be the single largest source of air pollution in coastal cities (Vujičić et al. 2013). Another study finds that HEV Class 8 HD vehicles achieve the highest performance in city driving with stop-and-go conditions that regenerate the battery and minimize durations at cruising speeds (Daw et al. 2013).

Although nickel-metal-hydride batteries are used in hybrid vehicles, lithium-ion (Li-ion) batteries offer lightweight properties, lower maintenance requirements, and minimal self-discharge characteristics, enabling Li-ion batteries to stay charged longer. The trend for HD vehicles with electric power drive is towards Li-ion batteries (Majeau-Bettez et al. 2011, Notter et al. 2010). Li-ion batteries consist mostly of heavy metals and plastics (Notter et al. 2010), with lithium itself representing a small fraction (typically between 1 and 3 percent) of total battery composition (Gaines et al. 2011).

One LCA study found that environmental impacts associated with HD Li-ion battery pack production is significantly higher than for a conventional diesel engine. For example, a battery pack with 140 kWh energy capacity provides close to the minimum performance required for larger HD vehicles. The GHG emissions needed to produce a 140 kWh Li-ion battery pack are estimated to be 37 $MTCO_2e$, considerably higher than the 3 $MTCO_2e$ for a conventional battery used with 8-liter 6-cylinder diesel engines. In addition, the HD vehicle itself has a functional lifespan twice the Li-ion battery, which will

necessitate at least one replacement, thereby doubling the associated "cradle to gate" associated emissions (Vujičić et al. 2013). Another study, by Sardar and Mubashir (2011), showed that the energy and GHG emissions from Li-ion battery manufacturing constitute a relatively small share of the full life-cycle energy and GHG emissions from a CNG PHEV urban city bus. This study, citing Samaras and Meisterling (2008), found that the total energy required for battery production was 311.1 gigajoule, or 5 percent of life-cycle energy consumption, and total CO_2 emissions from battery manufacturing were 53.14 metric tons, or 6.5 percent of life-cycle CO_2 emissions.

The detailed discussion of studies related to light-duty EVs presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS supported the following findings, which are also likely to be applicable to HD vehicles:

- Across the full vehicle life cycle, including the use stage, the impacts of upstream battery production are small (less than 10 percent across most environmental impact categories).
- Life-cycle emissions from BEVs and PHEVs vary based on the electricity grid mixes used for battery charging. Section 6.2.2 of the MY 2017–2025 CAFE standards Final EIS describes the life-cycle impacts of varying grid-mix assumptions.
- Most studies have not quantified the environmental impacts from recycling Li-ion batteries. The recycling market for Li-ion batteries is in its infancy, with limited feedstock, because EVs are still just a small segment of the vehicle market.

6.3.7 Tractor Auxiliary Power Units (APUs)

HD vehicle engine idling has recently been targeted as an area for environmental improvement. Vehicle engines are idled in order to power climate-control devices and sleeper compartment accessories in tractors during long-haul trips. HD vehicle engines are estimated to be idling 20 to 40 percent of their operation time, depending on the engine operation and season (Brodrick et al 2002). EPA estimated that 960 million gallons of fuel are consumed per year from idling commercial trucks alone, and the associated emissions from these activities account for 11 million tons of CO_2, 180,000 tons of NO_x, and 5,000 tons of particulate matter (Frey and Kuo 2009). Auxiliary power units (APUs) are designed to provide energy or electricity to vehicle tractors separate from the vehicle engine. As they are designed for just auxiliary power demands rather than vehicle propulsion, APUs are a more efficient option than vehicle idling for powering climate-control devices and other tractor accessories. Direct emissions from APUs are required to comply with small engine standards, and California requires additional emissions controls, such as a diesel particulate filter, for APUs on trucks built in 2007 or later (Gaines and Brodrick Hartman 2009). Two categories of APU technologies are commonly used in HD vehicles: external diesel power generator units and fuel cell units (both proton exchange membrane and solid oxide fuel cells).

Diesel-powered APUs have been shown to be an environmentally beneficial alternative to HD vehicle idling. A study by EPA (Lim 2002) evaluated the direct emissions reduction associated with a 2-cylinder diesel-powered APU when compared with idling a HD truck's engine for 3 hours. The author performed 42 tests on nine Class 8 trucks ranging in model year from the 1980s to 2001. The results show that the model year 2000 truck equipped with an APU was capable of reducing CO_2 emissions by 50 to 81 percent and NO_x emissions by 89 to 96 percent (Lim 2002). A study by Frey and Kuo (2009) showed similar findings when comparing an idling baseline engine with two diesel-powered APUs at various electrical loads (6 kW and 4 kW) over the course of a year. The diesel power generator APUs were estimated to reduce direct NO_x emissions by 80 to 90 percent and direct CO_2 emissions by 36 to 47 percent at mild ambient temperatures when compared with the default base engine idle speed of 600 revolutions per minute. Overall, the diesel APUs evaluated showed lower hourly energy use (gallons per hour) as well as fewer emitted pollutants per hour. The base case had an hourly energy use rate of 0.56

to 0.71 gallons-equivalent per hour, depending on if the air conditioning was on, whereas the APUs had an hourly energy rate of 0.22 to 0.55 gallons-equivalent per hour depending on the APU's power and the load. However, these energy and emissions savings do not account for the upstream emissions from the extraction and production of diesel fuel or from the manufacturing and transportation of the APU (Frey and Kuo 2009).

Fuel cell APUs have also emerged as an option for reducing the environmental impact of idling HD trucks. Proton exchange membrane (PEM) fuel cells use a proton-conducting polymer membrane as their electrolyte, which is sandwiched between two porous electrodes. As the fuel is fed into one side, the electrode splits it into protons and electrons. While the protons flow through the electrolyte, the electrons flow through the wires connecting the electrodes, creating a current. When the protons and electrons meet, they produce water as a waste stream (Barbir 2006). PEM fuel cells use hydrogen or methanol for fuel, operate at ambient temperature, and offer reductions in environmental impacts compared with both diesel APUs and engine idling (Barbir 2006, Brodrick et al. 2002). However, these studies have not evaluated the upstream emissions associated with the extraction and production of the fuel and the manufacturing of the fuel cell. Because PEM fuel cells are fueled by hydrogen, they have zero direct emissions of NO_x (Brodrick et al. 2002). However, PEM fuel cells have a very low tolerance for impurities in their fuel, requiring a supply of onboard hydrogen and thus making them less likely to be widely deployed (Jain et al. 2006). Solid oxide fuel cells (SOFCs) have a similar structure to PEM fuel cells but have an oxide-based ceramic electrolyte typically made of yttria-stabilized zirconia and can operate on diesel fuel (Jain et al. 2009). They operate at high temperatures (800 to 1,000°C) but are more tolerant to sulfur containments, which are typically found in diesel fuel (Jain et al. 2009). They produce the equivalent amount of power as a diesel generator with 46 percent less fuel, reducing direct emissions (Holt 2001). Biofuels have also been highlighted as a possible fuel source for SOFCs. Lin et al. (2011) notes that to supply 1 kWh of electricity, biodiesel produced from waste cooking oil has a life-cycle energy impact eight times less than that of an idling diesel engine. Further discussion of the life-cycle impacts of biofuels can be found in Section 6.2.3.

The life-cycle environmental impacts from APUs beyond the vehicle use phase are briefly covered in the literature. The results for both diesel-powered and fuel cell APUs indicate reduced environmental impacts when compared with idling a vehicle's engine for an extended period of time. A study by Gaines and Brodrick Hartman (2009) presents the life-cycle impacts of idling an HD truck engine running on conventional diesel fuel containing 500 parts per million sulfur with heating and cooling loads compared with a diesel-fueled APU with the same capacity for an average of 2,100 hours per year. Over the full diesel fuel cycle—including upstream fuel extraction, processing, and transport—the APU had an order of magnitude less NO_x, PM10, and CO_2 emissions when compared with idling. The annual energy use for the heating and cooling loads was three times less for the APU than engine idling (Gaines and Brodrick Hartman 2009). However, this analysis did not account for environmental impacts from manufacturing and transporting the equipment studied or end-of-life impacts.

A study by Baratto and Diweker (2005) evaluates the life-cycle environmental impacts of a small-scale SOFC system with an output of 1 to 10 kW as compared with internal combustion engine idling. The authors evaluated the environmental impacts from "all steps required to provide the fuel, to manufacture the [APU] device and to operate and maintain the vehicle through its lifetime up to disposal" but do not include impacts from disposal. The impacts from the APU are compared with the impacts from the internal combustion vehicle, including the "emissions from operation over a life time, fuel life cycle and system life cycle." The study results are normalized over a lifetime of 9,090 hours and evaluate a multitude of human health and environmental factors, including global warming potential, acidification, and human inhalation and dermal exposure. The authors found that the output rate of potential environmental impacts per second of diesel consumption for an internal combustion engine

idling over the lifetime of the technologies is three orders of magnitude larger than that of the SOFC analyzed (Baratto and Diweker 2005).

The literature review did not identify life-cycle studies quantifying either the environmental impacts from disposal of APUs or the fuel or freight efficiency impact from the APU's additional weight. APUs can weigh up to 600 lbs. (DOE 2013c). Additional research is needed on this topic to determine the life-cycle impacts of applying APUs with respect to production, disposal, freight efficiency, and vehicle fuel economy. NHTSA welcomes comments about or citations to additional studies addressing these issues.

6.4 Conclusions

The information in this chapter helps the decisionmaker by identifying the net life-cycle environmental reductions in environmental impacts achievable by various fuels, materials, and technologies, and the factors that contribute to increases or decreases in environmental impacts at other life-cycle stages beyond the vehicle use stage. The overarching conclusion based on this synthesis of the LCA literature considered is that most materials and technologies addressed appear to reduce GHG emissions, energy use, and most other environmental impacts when considered on a life-cycle basis. However, some technologies show uncertainty about environmental impacts from upstream production, which may, in some cases, counterbalance some portion of the environmental benefits when evaluated on a life-cycle basis.

6.4.1 Energy Source Conclusions

- The LCA literature synthesis revealed qualitative information about upstream NG and petroleum emissions to supplement the analyses in Chapters 4 and 5. In general, the LCA literature synthesis found that upstream emissions make up less than 20 percent of total life-cycle GHG emissions and less than 10 percent of most non-GHG life-cycle emissions. The following trends were identified during the LCA literature synthesis for energy source technologies:
- Likely alternative fuels for HD vehicles, compared with conventional truck fuels, produce net lower life-cycle GHG emissions.
- CNG powered HD vehicles and potential scenarios for LNG HD vehicles can produce net lower life-cycle GHG emissions.
- The upstream environmental impacts associated with extraction methods and methane leakage of natural gas are lower than for liquid petroleum.
- Biodiesel life-cycle emissions are lower than life-cycle emissions from conventional diesel.
- Both ethanol and electric power are applications that could also reduce the life-cycle emissions for trucks but are not expected to comprise a significant part of future truck fleets.

6.4.2 Materials and Technologies Conclusions

The magnitude of life-cycle impacts associated with materials and technologies likely to be used to improve HD vehicle fuel efficiency is small in comparison with the emission reductions from avoided fuel consumption during vehicle use. This LCA literature synthesis identified some qualitative information about those impacts to supplement the analyses in Chapters 4 and 5.

The LCA literature synthesis revealed the following trends for materials and technologies considered.

- Materials manufactured using aluminum, high-strength steel, composites, magnesium, and titanium also require more energy to produce than similar conventional steel components.
- Weight-reducing manufacturing—such as hydro-forming, laser welding, and 3D printing—requires new equipment to produce HD vehicles.
- However, upstream energy requirements associated with the new equipment are small compared to the operating efficiencies gained, leading to a net decrease in environmental impacts.
- Materials manufactured using aluminum, high-strength steel, composites, magnesium, and titanium also require more energy to produce than similar conventional steel components.
- As with the manufacturing advances, upstream energy requirements associated with the alternative materials are small compared to the operating efficiencies gained, leading to a net decrease in environmental impacts.
- The adoption of HD hybrid and APU technologies is also likely to yield lower environmental impacts on a life-cycle basis.
- There are performance trade-offs associated with aerodynamic features and LRR tires. Aerodynamic features add weight and have associated upstream energy requirements. LRR tires require considerably more energy to produce than conventional products. The current state of LCA scientific understanding on aerodynamic features and LRR tires is still evolving.
- For several technologies—including trailers, aerodynamics and drag, tires, and APUs—further research is needed on life-cycle impacts. NHTSA welcomes comments about or citations to additional studies addressing these issues.

CHAPTER 7 OTHER IMPACTS

This chapter describes the affected environment and environmental consequences of the Proposed Action and alternatives on potential impact areas other than those described in Chapter 3, *Energy*, Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, of this EIS. These additional potential impact areas include hazardous materials and regulated waste (Section 7.1), historic and cultural resources (Section 7.2), noise (Section 7.3), safety impacts on human health (Section 7.4), and environmental justice (Section 7.5). This chapter also addresses unavoidable adverse impacts (Section 7.6), short-term uses and long-term productivity (Section 7.7), and irreversible and irretrievable commitments of resources (Section 7.8). With respect to each of these issues, because the magnitude of the changes that each alternative would generate is too small to address quantitatively, impacts on the resources and topics discussed in this chapter are described qualitatively in relation to the Proposed Action. Consequently, the discussions of impacts in this section do not distinguish among the alternatives. With regard to Section 7(a)(2) of the Endangered Species Act (16 U.S.C. § 1536(a)(2)), NHTSA incorporates by reference its response beginning on page 9-101 of the MY 2017–2025 CAFE Final EIS (NHTSA 2012). For that rulemaking, NHTSA concluded that a Section 7(a)(2) consultation was not required because any potential for a specific impact to particular listed species and their habitats associated with emissions changes achieved by that rulemaking were too uncertain and remote to trigger the threshold for such a consultation. That conclusion, based on the discussion and analysis included therein, applies here to the fuel consumption and GHG emission reductions anticipated to occur under the Proposed Action.

7.1 Hazardous Materials and Regulated Waste

7.1.1 Affected Environment

Hazardous waste is defined here as any item or agent (biological, chemical, or physical) that has the potential to cause harm to humans, animals, or the environment, either by itself or through interaction with other factors. Hazardous waste is generally designated as such by individual states or the U.S. Environmental Protection Agency (EPA) under the Resource Conservation and Recovery Act of 1976. Additional federal and state legislation and regulations, such as the Federal Insecticide, Fungicide, and Rodenticide Act, determine handling and notification standards for other potentially toxic substances. For the Proposed Action, the relevant sources of impacts from hazardous materials and waste are oil extraction and refining processes, agricultural production and mining activities, and vehicle batteries.

Hazardous waste produced from oil and gas extraction and refining can present a threat to human and environmental health. Onshore environmental effects result mostly from the improper disposal of saline water that was produced with oil and gas (referred to as “produced water”), from accidental releases of hydrocarbons and produced water, and from oil wells that were improperly sealed when abandoned (Kharaka and Otton 2003). Produced water from oil and gas wells often contains high concentrations of total dissolved solids in the form of salts. These wastewaters could also contain various organic chemicals, inorganic chemicals, metals, and naturally occurring radioactive materials (EPA 2013). The development of new techniques, such as hydraulic fracturing, has led to vast new reserves of natural gas becoming available in the United States. The extraction of natural gas from shale can affect drinking water quality from gas migration, contaminant transport through factures, wastewater discharge, and accidental spills (Vidic et al. 2013). This has led some states, including New York, Illinois, Pennsylvania, and Colorado, to limit hydraulic fracturing near aquifers (FracFocus 2014). Offshore effects result from improperly treated

produced water that gets released into the water surrounding an oil platform (EPA 1999). Offshore platform spills, although relatively rare,[1] can have devastating environmental impacts. According to the American Petroleum Institute, more than 18 billion barrels of waste fluids, including produced water and associated waste, from oil and gas production are generated annually in the United States (EPA 2012b).

The oil extraction process that is used to produce fuel for the operation of motor vehicles results in emissions that affect air quality from the combustion of petroleum-based fuels, which releases volatile organic compounds (VOCs), sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), and other air pollutants (NAP 2014). In the atmosphere, SO_2 and NO_X contribute to the formation of acid rain (the deposition of SO_2 and NO_X under wet, dry, or fog conditions), which enters bodies of water either directly or as runoff from terrestrial systems (*see* Chapter 4, *Air Quality*, for more information on air quality), with negative impacts on water resources, plants, animals, and cultural resources. Oil extraction activities could also affect biological resources through habitat destruction and encroachment, raising concerns about their impacts on the preservation of animal and plant populations and their habitats.

The production and disposal of batteries is another relevant source of potential impacts related to regulated waste. Batteries, such as those used in hybrid vehicles, are considered universal waste by EPA (40 CFR Part 273) and, therefore, can be recycled under the streamlined collection standards that facilitate environmentally sound collection and proper recycling and treatment.

HD vehicles could incorporate hybrid power trains and on-board energy storage systems (batteries). Hybridization is found to be most beneficial in transit buses, Class 2b pickups and vans, Class 8 refuse trucks, and Classes 3–6 box and bucket trucks (ORNL 2013). Battery-powered motors are not as practical for long-haul HD trucks with high daily vehicle miles traveled (VMT) but could be an option for service fleets, such as Class 2b and 3 vehicles, that perform local deliveries or other jobs during the day and can be plugged in and charged overnight (NRC 2014). The range of commercial electrochemical battery types that are either currently available or under development for use in HD hybrid electric vehicles (HEVs) involve different environmental considerations vis-à-vis potential releases of component materials. Examples include advanced lead acid (PbA), conventional nickel cadmium (NiCd) and nickel metal hydride (NiMH), and sodium nickel chloride (NaNiCl) batteries, and multiple options are emerging for lighter and higher capacity lithium ion (Li-ion) batteries. These battery types encompass a broad range of potential battery chemistries with diverse performance, safety, and toxicity tradeoffs.

Waste produced from the life cycle of vehicle batteries varies, depending on material composition. During the life cycle of batteries, the potential exists for resource extraction, production, manufacturing, and disposal to generate waste, which would contribute to air pollution and landfill waste. In addition, resource extraction related to the production of electric motors (the mining of rare earth metals, for example) could lead to air pollution, water quality degradation, and other impacts. Although effective techniques to recycle electric vehicle batteries have been developed, electric battery recycling is still relatively low given that few electric batteries have reached the end of their life. In addition, it is currently cheaper to mine for new lithium than to extract it from used batteries. If not addressed, increased use of batteries in hybrid vehicles and auxiliary power or HVAC units, combined with the lack of battery recycling, could lead to increased waste from batteries.

[1] Historically, there were six spills per one hundred billion barrels of oil produced from offshore oil platforms between 1964 and 2010 (Anderson et al. 2012).

7.1.2 Environmental Consequences

The projected reduction in fuel production and combustion as a result of the Proposed Action (*see* Section 3.3 for projected fuel consumption and savings) could lead to a reduction in petroleum extraction and refining for the transportation sector. Waste produced during the petroleum refining process is released primarily into the air (75 percent of total waste) and water (24 percent of total waste) (EPA 1995). EPA defines a release as the "on-site discharge of a toxic chemical to the environment…emissions to the air, discharges to bodies of water, releases at the facility to land, as well as contained disposal into underground injection wells" (EPA 1995). EPA reports that nine of the 10 most common toxic substances released by the petroleum refining industry are volatile chemicals (i.e., highly reactive substances that are prone to state changes or combustion, including benzene, toluene, ethylbenzene, xylene, cyclohexane, ethylbenzene, and 1,2,4-trimethylbenzene) (EPA 1995). These substances are present in crude oil and finished petroleum products. Other potentially dangerous substances that are commonly released during the refining process include ammonia, gasoline additives (methanol, ethanol, and methyl tert-butyl ether), and chemical feedstocks (propylene, ethylene, and naphthalene) (EPA 1995). Spent sulfuric acid is by far the most commonly produced toxic substance; it is generally reclaimed, however, rather than being released or transferred for disposal (EPA 1995).

Spills of oil or other hazardous materials during oil and gas extraction and refining can lead to surface- and groundwater contamination and result in impacts on drinking water and marine and freshwater ecosystems. Of the volume of oil spilled in "harmful quantities" (as defined under the Clean Water Act), EPA estimates that 83.8 percent was deposited in internal/headland waters and within 3 miles of shore, while 17.5 percent spilled from pipelines, often in inland areas (EPA 2004). The potential reduction in petroleum extraction and refining that would result from the Proposed Action could result in a decreased risk of hazardous material spills during extraction and refining processes.

Several of the produced VOCs emitted through oil and gas extraction and refining contribute to ground-level ozone and smog and are known or suspected carcinogens (EPA 2011). Many others are known to cause respiratory problems and impair the function of internal organs, particularly the liver and kidneys (EPA 2011). Potentially dangerous substances that are commonly released during the refining process include ammonia, gasoline additives (methanol, ethanol, and methyl tertiary butyl ether), chemical feedstocks (propylene, ethylene, and naphthalene), benzene, toluene, ethylebenzene, xylene, and n-hexane (EPA 2011). Ammonia is a form of nitrogen and can contribute to eutrophication[2] in surface water bodies. Once present in a surface water body, air pollutants can cause acidification of the water body, changing the pH of the system and affecting the function of freshwater ecosystems. Plants and animals in a given ecosystem are highly interdependent because of the many connections between them; changes in pH or aluminum levels can, therefore, severely affect biodiversity (EPA 2008b). As lakes and streams become more acidic, the numbers and types of fish as well as aquatic plants and animals in these water bodies could decrease.

Benzene exposure could cause eye and skin irritation over the short term as well as blood disorders, reproductive and developmental disorders, and cancer (EPA 2011). Exposure to toluene emissions over the long term could cause nervous system effects, skin and eye irritation, dizziness, headaches, difficulty sleeping, and birth defects (EPA 2011). Short-term exposure to ethylbenzene emissions could cause throat and eye irritation, chest pain and pressure, and dizziness, and long-term exposure could cause blood

[2] The process by which an aquatic ecosystem becomes enriched in artificial or natural substances (such as nitrates or phosphates) that help stimulate the growth of plant life, resulting in the depletion of dissolved oxygen.

disorders (EPA 2011). Short-term exposure to xylene emissions could cause nose, eye, throat, and gastric irritation; nausea; vomiting; and neurological effects. Long-term exposure could affect the nervous system (EPA 2011). Short-term exposure to n-hexane emissions could cause dizziness, nausea, and headaches, and long-term exposure could cause numbness in extremities, muscular weakness, blurred vision, headaches, and fatigue (EPA 2011).

Oil exploration and extraction result in intrusions into onshore and offshore natural habitats and can involve construction within natural habitats. There are serious environmental concerns regarding ecosystems that experience encroachment and the effects of drilling on benthic (bottom-dwelling) populations, migratory bird populations, and marine mammals (Borasin et al. 2002).

Acid rain caused from the release of VOCs has been shown to affect forest ecosystems negatively, both directly and indirectly. These impacts include stunted tree growth and increased mortality, primarily as a result of the leaching of soil nutrients (EPA 2012a). Declines in the biodiversity of aquatic species and changes in terrestrial habitats have most likely had ripple effects on wildlife species that depend on these resources. The eutrophication of aquatic systems, which can ultimately result in the death of fish and aquatic animals, is enhanced by acid rain (Lindberg 2007). Damage from acid rain also substantially reduces the societal value of buildings, bridges, and cultural objects made from materials such as bronze, marble, or limestone (*see* Section 7.3). The projected reduction in fuel production and combustion as a result of the Proposed Action could reduce pollutant emissions that cause acid rain.

HD vehicles and equipment, as well as businesses engaged in the manufacture and assembly of HD vehicles, produce hazardous materials and toxic substances. EPA reports that solvents (xylene, methyl ethyl ketone, acetone, etc.) are the most commonly released toxic substances of those that the agency tracks for this industry (EPA 1995). These solvents are used to clean metal and are also used in the vehicle finishing process during assembly and painting (EPA 1995). Other industry waste includes metal paint and component-part scrap. Solvents can present health hazards to those who come into contact with them such as toxicity to the nervous system, reproductive damage, liver and kidney damage, respiratory impairment, cancer, and dermatitis (OSHA 2014).

To comply with the proposed standards, manufacturers could incorporate a number of technologies for electrification, including HEVs, electrified accessories, fully electric power trains, electrified power take-off units, plug-in HEVs, external-power-to-electric-power trains for zero-emissions vehicle corridors, and alternative fuel/hybrid combinations (NRC 2014). Most current HEVs use nickel-metal-hydride or sodium-nickel-chloride batteries, but the trend for the near future for all HD electric vehicles is a shift toward Li-ion batteries (Majeau-Bettez et al. 2011). The Li-ion battery is the preferred battery technology because it is composed of lightweight materials, has comparatively low maintenance requirements, is able to stay charged longer, and meets the specific power and energy requirements of HD vehicles (Notter et al. 2010, Lee et al. 2011). *See* Chapter 6, *Life-cycle Assessment*, for further details.

The proposed standards could induce increases in production and the use of electrochemical batteries for HD HEVs.[3] For instance, battery-powered Auxiliary Power Unit (APU) and Battery Air Conditioning (BAC) systems are idle control technologies that store electricity in batteries to provide accessory power and/or cooling to the truck when stationary. Some versions of waste heat recovery systems generate electricity to charge a high-voltage battery, which in turn, is used to drive a hybrid powertrain system.

[3] In addition to electrochemical batteries, other energy storage technologies, which were not considered here, could be applied to hybridize heavy-duty powertrains. Examples include ultracapacitors, high-speed flywheels, and hydraulic accumulators.

Stop-start or mild-hybrid technologies may increase the size of the battery or induce a switch to a higher capacity battery technology. All electric vehicles and many hybrid electric vehicles store energy in large battery systems to drive or supplement the power train. While the Phase 2 proposal discontinues the Phase 1 Advance Technology Credits for hybrid power trains in favor of testing, it proposes to allow the Phase 1 credits to be carried over into Phase 2 for a period of 5 years. In this regard, Phase 2 may further incentivize hybrid vehicle production for credit carry-over purposes. Because of the uncertainty surrounding which battery types and chemistries might be used by HD vehicles, NHTSA has not attempted to quantify the environmental impacts of increased battery production.

As mentioned previously, batteries such as those used in HEVs are considered universal waste by EPA under 40 CFR Part 273 and, therefore, can be collected under streamlined collection standards that facilitate environmentally sound collection and proper recycling and treatment. Life-cycle analysis of the material resource, energy intensiveness, and environmental issues associated with production, operation, and disposal of automotive batteries is an active area of research, especially regarding advanced Li-ion chemistries for HEVs and EVs. *See* Chapter 6, *Life-cycle Assessment*, for further details.

The production, use, and disposal of different types of electric batteries generate different types of waste. Both solid and hazardous waste are produced during the life cycle of the batteries, including during production and after their useful life in automobiles. Of the two main materials in electric batteries, nickel is classified as a hazardous air pollutant and hazardous waste, but lithium is not listed in either category (EPA 2010a, 40 CFR Part 261.33). The disposal of batteries can lead to adverse impacts because of the risk of toxic chemicals being released into the environment. At the end of the useful life of an electric vehicle or plug-in HEV, the battery will most likely not be fully exhausted and could be used for other purposes (EPA, NHTSA, and CARB 2010) to mitigate environmental impacts. When these batteries can no longer be reused, most of the materials can then be reprocessed and recycled. *See* Chapter 6, *Life-cycle Assessment*, for further details.

All of the alternatives could lead to the use of some lighter weight materials and advanced technologies in HD vehicles, depending on the mix of methods the manufacturers use to meet the proposed HD vehicle fuel efficiency standards, economic demands from consumers and other manufacturers, and technological developments. If manufacturers pursue vehicle downweighting in response to the proposed standards, a net increase in the waste stream could occur because of an increase in the amount of waste during the refining process related to the use of lighter weight materials in vehicle manufacturing, which would involve refining aluminum or manufacturing plastic (Schexnayder et al. 2001). Because there is still substantial uncertainty regarding how manufacturers would choose to comply with the standards, including whether they would use lighter weight materials, this EIS does not quantify effects related to waste produced during the refining process due to downweighting.

In summary, the projected reduction in fuel production and consumption as a result of the Proposed Action could lead to a reduction in the amount of hazardous materials and waste created by the oil extraction and refining industries. NHTSA expects corresponding decreases in the associated environmental and health impacts of these substances. Any increase in the electrification and hybridization of the HD vehicle fleet resulting from the Proposed Action would increase the amount of waste from batteries compared with the amount produced under Alternative 1 (No Action Alternative); however, these effects would most likely be small if their occurrence is related to the repurposing, recycling, and reprocessing of batteries.

7.2 Historic and Cultural Resources

7.2.1 Affected Environment

Section 106 of the National Historic Preservation Act of 1966 (16 U.S.C. 470 et seq.), and its implementing regulations at 36 CFR Part 800, states that agencies of the Federal Government must take into account the impacts of their actions on historic properties. This process, known as the Section 106 process, is intended to support historic preservation and mitigate impacts on significant historical or archaeological properties through the coordination of federal agencies, states, and other affected parties. Historic properties are generally identified through the National Register of Historic Places, which lists properties of significance to the United States or a particular locale because of their setting or location; contribution to, or association with, history; or unique craftsmanship or materials.[4]

7.2.2 Environmental Consequences

Acid rain, the primary source of which is the combustion of fossil fuels, is one cause of degradation to exposed cultural resources and historic sites (EPA 2012a). EPA states that the corrosion of metals and the deterioration of paint and stone can be caused by both acid rain and the dry deposition of pollution, which can reduce the cultural value of buildings, statues, cars, and other historically significant materials (EPA 2012a). Deposition of dry acidic compounds found in acid rain can also dirty historic buildings and structures, causing visual impacts and increased maintenance costs (EPA 2012a). The projected reduction in fuel production and combustion as a result of the Proposed Action and alternatives could lead to a reduction in the amount of pollutant emissions that cause acid rain. A decrease in the emissions of such pollutants could result in a corresponding decrease in the amount of damage to historic and other structures caused by acid rain. However, such effects are not quantifiable because of the inability to distinguish between acid rain deterioration and natural weathering (rain, wind, temperature, and humidity) impacts on historic buildings and structures and the varying impact of a specific geographic location on any particular historical resource (Striegel et al. 2003).

All action alternatives are expected to result in fewer adverse impacts, including a reduction in acid rain deposition, as a result of the reduction in vehicle emissions compared with the No Action Alternative. Consequently, historic and cultural resources could be expected to benefit from reduced air quality and climate change impacts under the action alternatives.

7.3 Noise

7.3.1 Affected Environment

Vehicle noise is composed primarily of the interaction between the power train, tire/pavement, and vehicle aerodynamics. The interaction between road surfaces and tires is the primary source of noise from vehicles traveling on highways at high speeds (NAE 2010). According to EPA, approximately four to eight times as many people are exposed to highway traffic noise with Day-Night Average Sound Level (DNL)

[4] National Register–eligible properties must also be sites that meet one or more of the following criteria (36 CFR § 60.4): are associated with events that have made a significant contribution to the broad patterns of our history; are associated with the lives of persons significant in our past; embody the distinctive characteristics of a type, period, or method of construction or represent the work of a master or possess high artistic values or represent a significant and distinguishable entity whose components may lack individual distinction; have yielded, or may be likely to yield, information important in prehistory or history.

values of more than 65 decibels (dB) than are exposed to aircraft and rail noise. Road traffic noise is expected to highly annoy approximately 30 percent of people exposed to these DNL values (NAE 2010). Traffic noise levels are greatly influenced by the vehicle fleet mix traveling over the highway or roadway. Based on FHWA traffic noise modeling, noise levels for HD vehicles[5] traveling at speeds of more than 50 miles per hour (mph) are between 80 and 90 dB, which are approximately 10 dB higher than noise levels for light-duty vehicles at similar speeds. Modeled noise levels for medium-duty vehicles[6] fall between those for light-duty and HD vehicles, averaging between 75 and 85 dB at speeds of more than 50 mph (NAE 2010). EPA has set a noise emissions limit of 80 dB for all new medium- and heavy-duty trucks in excess of 10,000 pounds (40 CFR § 205.52).

The noise generated from air flowing over a vehicle, or wind noise, is directly related to the aerodynamics of a vehicle. For example, vertical exhaust pipes, "classic" or square frontal designs, and side mirrors all increase vehicle aerodynamic drag, thereby contributing to increased wind noise. To reduce wind noise, some vehicle features can be re-designed to lower aerodynamic drag, in some cases by being incorporated into the interior of the vehicle (Jiang et al. 2011). This method of reducing wind noise by improving vehicle aerodynamics is referred to as aero-acoustics. The largest sources of wind noise for HD vehicles are for the A-pillar[7] and mirrors of Class 8 combination tractors (National Research Council Canada 2012). Excessive amounts of noise can present a disturbance and a hazard to human health at certain levels. Potential health hazards related to noise range from annoyance (sleep disturbance, lack of concentration, and stress) to hearing loss at high levels (Passchier-Vermeer and Passchier 2000). Primary sources of noise in the United States include road and rail traffic, air transportation, and occupational and industrial activities (Hammer et al. 2013). Noise from motor vehicles has been shown to be one of the primary causes of noise disturbance in homes (Theebe 2004, Ouis 2001). Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort for occupants of other vehicles, pedestrians and other bystanders, and residents or occupants of surrounding property.

Wildlife exposure to chronic noise disturbances from motor vehicles can impair senses; change the habitat use, density, and occupancy patterns of species; increase stress response; modify pairing and reproduction; increase predation risk; degrade communication; and damage hearing if the sound is sufficiently loud (Barber et al. 2010, Bowles 1995, Larkin et al. 1996, Brown et al. 2013). Although noise can affect wildlife, it does not mean the effect is always adverse. Wildlife species are exposed to many different noises in the environment and can adapt. Even without human-generated noise, natural habitats have particular patterns of ambient noise resulting from, among other things, wind, animal and insect sounds, and noise-producing environmental factors, such as streams and waterfalls (California Department of Transportation 2007).

7.3.2 Environmental Consequences

Under all of the alternatives, NHTSA predicts that HD vehicle use would increase because of projected trends in VMT growth, resulting in increases in vehicle road noise. To comply with the proposed standards, however, manufacturers could reduce vehicle mass or increase the production of hybrid vehicles, which could lead to some reduction in the amount of exterior noise produced by motor vehicles.

[5] This includes any vehicles within Classes 6–-8 with three or more axles. HD vehicles, in this instance, exclude buses because they are a separate vehicle category for the purposes of highway traffic noise analyses (FHWA 2011).

[6] In this instance, medium-duty vehicles include only those vehicles with two axles and six tires (FHWA 2010). These vehicles are in Classes 2b–5.

[7] A standard vehicle has three pillars, A, B, and C. The A-pillars hold either side of the windshield in place. The B-pillars start where the driver's and passenger's side windows end. The C-pillars hold the sides of the vehicle's rear window in place.

In general, noise levels from HD vehicles are location specific, meaning that factors such as the time of day when increases in traffic occur, existing ambient noise levels, the presence or absence of noise abatement structures, and the location of schools, residences, and other sensitive noise receptors all influence whether there would be noise impacts. Location-specific analysis of noise impacts, however, is not possible given the available data. Instead, this section reports potential national-level changes in HD vehicle road noise resulting from the Proposed Action.

All of the action alternatives could lead to an increase in use of hybrid technologies, depending on the methods manufacturers use to meet the new requirements, economic demands from consumers and manufacturers, and technological developments. An increased percentage of hybrid technologies could result in reduced road noise, potentially offsetting some of the increase in road noise predicted to result from increased VMT. However, potential noise reductions achieved from an increase in the use of hybrid technologies could be offset at low speeds by manufacturer installation of pedestrian safety-alert sounds, as proposed by NHTSA (NHTSA 2013). Because uncertainty is substantial regarding how manufacturers would choose to comply with the standards, including whether they would use hybrid technologies, this EIS does not quantify the effects related to noise due to hybridization of HD vehicles. A recent study on noise emissions of a hybrid electric mid-size truck (Class 2b or 3) showed that, in electric mode, the vehicle could produce an 8 dB noise benefit or greater at low speeds (under 30 mph) (Pallas et al. 2014). The use of low-rolling-resistance tires and single wide-base tires could also decrease the amount of exterior noise, vibration, and harshness from tire/road friction (EPA 2010b). Manufacturers could also choose to adopt active engine mounts and/or active noise cancellation systems to address noise vibration and harshness (NVH) concerns. Active noise cancellation systems cancel low-frequency noise from the engine by using speakers to broadcast a wave-pattern that is half a cycle out of phase with the noise, thereby cancelling the other noise (Ross 2014).

All action alternatives could result in fewer adverse impacts as a result of improvements related to vehicle noise, including an increase in the use of hybrid and electrified vehicles and components, compared with the No Action Alternative. Consequently, human health and wildlife could benefit from reduced noise impacts under the action alternatives; however, this would depend on how vehicle manufacturers choose to comply with the MYs 2018 and beyond regulations and which vehicle technologies are implemented.

7.4 Safety Impacts on Human Health

NHTSA analyzed how future improvements in fuel efficiency in the medium- and heavy-duty sector might affect human health and welfare. Both HD vehicle safety and the rate of traffic fatalities were considered. The analysis conducted by NHTSA for the MY 2017–2025 Final Rule found that reducing the weight of heavier light trucks but maintaining their size had a neutral impact on safety, thereby being unlikely to have an effect that would be large enough to be detected in a statistical analysis of crash data.[8]

In the context of the current rulemaking for HD vehicle fuel efficiency and GHG emissions standards, one would expect that reducing the weight of HD vehicles would, if anything, have a positive impact on safety.[9] However, given the large difference in weight between light-duty vehicles and HD vehicles (especially HD vehicles with loads), the agencies believe that the impact of weight reductions for HD vehicles would have

[8] *Final Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2017–MY 2025 Passenger Cars and Light Trucks*, NHTSA, August 2012 (EPA-420-R-12-016).

[9] Class 7 and 8 vehicles may experience increases in the amount of freight hauled as a result of the Proposed Action, which would offset the vehicle mass reduction. However, HD vehicles (2b-3 and vocational) are expected to see a decrease in overall weight as a result of the Proposed Action.

a negligible impact on safety for these classes of vehicles. The agencies recognize that conducting further study and research on the interaction of mass, size, and safety is important to assist future rulemaking, and NHTSA expects that the ongoing collaborative interagency work to address this issue for the light-duty vehicle context might also inform the evaluation of safety effects for HD vehicles (NHTSA 2010).

In a recent study, the Transportation Research Board examined HD vehicle crash trends using a crash rate index (CRI). The CRI, which was compared against baseline data, showed distinct differences among crash trends for heavy- and medium-duty trucks. The trend analysis showed that although crash rates for heavy-duty trucks are decreasing, the rate of this decline is slowed by the contrary trends observed in medium-duty trucks (NAP 2014). Similarly, a 2013 study analyzed the impact of vehicle mass and design updates to meet new light-duty fuel efficiency standards on total vehicle fatalities. The study found that mass reduction is associated with a small increase in risk from cars with lighter than average weights. However, this small increase is overshadowed by other vehicle, driver, and crash behaviors and characteristics. Overall, mass reduction in light-duty vehicles can be associated with an increase in crash frequency but a decrease in risk per crash (Wenzel 2013).

All action alternatives could result in fewer adverse impacts as a result of improvements in vehicle safety performance compared with the No Action Alternative. Consequently, human health and welfare could benefit from improved safety performance and fewer traffic fatalities under the action alternatives; however, this would depend on how vehicle manufacturers choose to comply with the MYs 2018 and beyond regulations and which vehicle technologies are implemented.

7.5 Environmental Justice

Executive Order (EO) 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[10] directs federal agencies to "promote nondiscrimination in federal programs substantially affecting human health and the environment, and provide minority and low-income communities access to public information on, and an opportunity for public participation in, matters relating to human health or the environment." EO 12898 also directs agencies to identify and consider any disproportionately high and adverse human health or environmental effects that their actions might have on minority and low-income communities and provide opportunities for community input in the NEPA process. The Council on Environmental Quality (CEQ) has provided agencies with general guidance on how to meet the requirements of the EO as it relates to NEPA (CEQ 1997c).

DOT Order 5610.2(a), *Department of Transportation Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[11] describes the process for DOT agencies to incorporate environmental justice principles in programs, policies, and activities. It also defines the terms *minority* and *low-income* in the context of DOT's environmental justice analyses. *Minority* is defined as a person who is black, Hispanic or Latino, Asian American, American Indian or Alaskan Native, or Native Hawaiian or other Pacific islander. *Low-income* is defined as a person whose household income is at or below the Department of Health and Human Services poverty guidelines.

On August 4, 2011, the Secretary of Transportation, along with heads of other federal agencies, signed a Memorandum of Understanding on environmental justice and EO 12898, affirming the continued

[10] *See* Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, 59 *Federal Register* 7629 (February 16, 1994).
[11] *See* Department of Transportation Updated Environmental Justice Order 5610.2(a), 77 *Federal Register* 27534 (May 10, 2012).

importance of identifying and addressing environmental justice considerations in agency programs, policies, and activities. As part of the Memorandum of Understanding, each federal agency agreed to review and update its existing environmental justice strategy as appropriate and publicize the updated strategy. Accordingly, DOT has reviewed and updated its environmental justice strategy to ensure that it continues to reflect its commitment to environmental justice principles and integrating those principles into DOT programs, policies, and activities (DOT 2014a). DOT also continues to provide annual implementation reports that detail specific actions and ongoing work to achieve environmental justice goals within the Department (DOT 2014b).

7.5.1 Affected Environment

The affected environment for this Proposed Action is nationwide, with a focus on areas that could contain low-income and minority communities and would be most likely to be exposed to the environmental and health effects of oil production, distribution, and consumption or the impacts of climate change. This includes areas where oil production and refining occur, areas in the vicinity of roadways, and urban areas that are subject to the heat island effect.[12]

There is evidence that proximity to oil refineries might be correlated with incidences of cancer and leukemia (Pukkala 1998, Chan et al. 2006, Bulka et al. 2013). Proximity to high-traffic roadways could result in adverse cardiovascular and respiratory effects, among other possible impacts (HEI 2010, Heinrich and Wichmann 2004, Salam et al. 2008, Samet 2007, Adar and Kaufman 2007, Wilker et al. 2013, Hart et al. 2013). Climate change can affect overall global temperatures, which could, in turn, affect the number and severity of outbreaks of vector-borne illnesses (USGCRP 2014). Chapter 3, *Energy*, Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, of this EIS discuss the connections between oil production, distribution, and consumption and their health and environmental impacts. The following paragraphs describe the extent to which minority and low-income populations might be more exposed or vulnerable to such effects.

Studies have found mixed evidence regarding whether there is a correlation between proximity to oil refineries and the prevalence of low-income and minority populations (Fischbeck et al. 2006) or have cited anecdotal evidence (O'Rourke and Connolly 2003). There is some evidence of proximity of low-income and minority populations to other types of industrial facilities (Mohai et al. 2009, Graham et al. 1999, Jerrett et al. 2001). It is unclear whether any correlation between the location of industrial facilities and the presence of minority and low-income populations is due to the facility siting process or real estate market dynamics and migration after the facilities are sited (Pastor et al. 2001, Graham et al. 1999, Morello-Frosch 2002). Performing a multivariate statistical analysis, Graham et al. (1999) found little support for the hypothesis that minority or low-income populations are more likely to live near oil refineries.

It is also unclear whether there is a disproportionate prevalence of minority and low-income populations living near mobile sources of pollutants. Although there is some evidence that higher traffic levels depress property values and attract lower income populations, urban development can increase traffic on secondary roads and affect relatively expensive housing (O'Neill et al. 2003). Inner-city populations, often low income and minority, might be more exposed to diesel exhaust emissions from buses and trucks (O'Rourke and Connolly 2003). More recent studies have demonstrated a correlation between

[12] The heat island effect refers to developed areas having higher temperatures than surrounding rural areas. *See* Section 5.5.1.5 for further discussion of the heat island effect.

low-income and minority status and proximity to roadways at the national level. For example, Rowangould (2013) found that greater traffic volumes and densities at the national level are associated with larger shares of minority and low-income populations living in the vicinity. Similarly, Kingsley et al. (2014) found that schools with minority and underprivileged[13] children were disproportionately located within 250 meters of a major roadway.

Some of the areas that are most vulnerable to climate change tend to have a higher concentration of minority and low-income populations, potentially putting these communities at higher risk from climate variability and climate-related extreme weather events (USGCRP 2014). For example, urban areas tend to have pronounced social inequities that could result in disproportionately larger minority and low-income populations than those in the surrounding non-urban areas (USGCRP 2014). Urban areas are also subject to the most substantial temperature increases from climate change because of the urban heat island effect (Knowlton et al. 2007, USGCRP 2014). Taken together, these tendencies demonstrate a potential for disproportionate impacts on minority and low-income populations in urban areas. Low-income populations in coastal urban areas, which are vulnerable to increases in flooding as a result of projected sea-level rise, larger storm surges, and human settlement in floodplains, could also be disproportionately affected by climate change because they are less likely to have the means to evacuate quickly in the event of a natural disaster and, therefore, are at greater risk of injury and loss of life (USGCRP 2009, USGCRP 2014).

Independent of proximity to sources of pollution or locations that would be disproportionately affected by climate change, low-income and minority populations might be more vulnerable to the health impacts of pollutants and climate change. The *2010 National Healthcare Disparities Report* stated that minority and low-income populations tend to have less access to health care services, and the services received are more likely to suffer with respect to quality (HHS 2003). Increases in heat-related morbidity and mortality as a result of higher overall and extreme temperatures are likely to affect minority and low-income populations disproportionately, partially as a result of limited access to air-conditioning and high energy costs (EPA 2009e, O'Neill et al. 2005, USGCRP 2014).

7.5.2 Environmental Consequences

The reduction in fuel production and consumption projected as a result of the proposed standards could lead to a minor reduction in the amount of direct land disturbance resulting from oil exploration and extraction as well as a reduction in the amount of air pollution produced by oil refineries. To the extent that minority and low-income populations live in greater proximity to oil extraction, distribution, and refining facilities, they would be more likely to benefit from the Proposed Action, but as noted, there is mixed evidence regarding whether this is the case.

Under the action alternatives, emissions of all criteria and hazardous air pollutants are anticipated to decline. However, as discussed in Chapter 4, *Air Quality*, the overall decrease in emissions predicted to occur as a result of the Proposed Action is not evenly distributed because of the increase in VMT from the rebound effect and regional changes in upstream emissions. As a result, emissions of some criteria and hazardous air pollutants are predicted to increase in some air quality nonattainment areas in some years. Minority and low-income populations could be more vulnerable to the adverse consequences of

[13] Public schools were determined to be predominantly "underprivileged" if they were eligible for Title I programs (federal programs that provide funds to school districts and schools with high numbers or high percentages of children who are disadvantaged) or had a majority of students who were eligible for free/reduced-price meals under the National School Lunch and Breakfast Programs.

these increases in hazardous air pollutants in certain nonattainment areas, as discussed in Section 7.5.1. Also, to the extent that minority and low-income populations live and travel in neighborhoods where there is a greater presence of older trucks (therefore a greater presence of vehicles that are not subject to the Proposed Action), they would be less affected by the changes in air quality that would result from the Proposed Action.

Because many of the changes in emissions are projected to be relatively small, no disproportionately high and adverse impacts on minority and low-income populations would be expected. In terms of air quality in nonattainment areas where increases in some air pollutants are expected in some years, minority and low-income populations could be more vulnerable to these changes, as discussed in Section 7.5.1. In terms of climate, all action alternatives are expected to result in fewer adverse impacts as a result of climate change compared with the No Action Alternative. Consequently, minority and low-income populations could be expected to benefit from reduced climate change impacts under the action alternatives.

7.6 Unavoidable Adverse Impacts

As demonstrated in Chapters 3, 4, and 5, the more stringent HD vehicle fuel efficiency standards under each of the action alternatives are projected to result in a net decrease in energy consumption and a reduction in all criteria and hazardous air pollutant emissions compared with the No Action Alternative. Despite these relative reductions, total energy consumption and total HD vehicle emissions under all alternatives are anticipated to increase as a result of projected increases in the number of HD vehicles in use and the total number of miles they are driven each year (as measured by VMT). This increased VMT predicted under all of the alternatives could result in unavoidable adverse impacts, specifically impacts on climate and air quality, if other actions are not taken in addition to the proposed action to minimize these long-term emissions trends.

Certain impacts, such as increased global mean surface temperature, sea-level rise, and increased precipitation, are likely to occur as a consequence of accumulated total GHG emissions in Earth's atmosphere. Neither the Proposed Action nor the other action alternatives alone would prevent these emissions and their associated climate change impacts. As described in Section 5.4, each of the action alternatives would reduce GHG emissions compared with projected levels under the No Action Alternative, thereby diminishing anticipated climate change impacts. Nonetheless, climate impacts would be expected under all action alternatives.

Regarding air quality, all criteria and hazardous air pollutants would exhibit decreases in emissions under all action alternatives and analysis years compared with their levels under the No Action Alternative. Consequently, any adverse impacts on human health associated with these emissions would be expected to be reduced, and no unavoidable adverse impacts from these emissions would be anticipated. However, increases in emissions of some pollutants could occur under certain action alternatives and analysis years in some nonattainment areas because of increases in VMT and diesel-powered APUs. Therefore, the potential for unavoidable adverse impacts on air quality from these emissions would depend on the final HD vehicle fuel efficiency standards that are selected. Despite these variations in pollutant emissions across alternatives and by region, overall U.S. health impacts associated with air quality (mortality, asthma, bronchitis, emergency room visits, and work-loss days) are anticipated to decrease with increasing fuel efficiency across all alternatives compared with the No Action Alternative. Correspondingly, monetized health benefits are also anticipated to increase under all action alternatives.

7.7 Short-Term Uses and Long-Term Productivity

All of the action alternatives would result in a decrease in crude oil consumption and reduced GHG emissions (and associated climate change impacts) compared with the No Action Alternative. To meet the proposed fuel efficiency standards, manufacturers would need to apply various fuel-saving technologies during the production of HD vehicles. NHTSA cannot predict with certainty which specific technologies and techniques manufacturers would apply or in what order. Some HD vehicle manufacturers might need to commit additional resources to existing, redeveloped, or new production facilities to meet the standards. Such short-term uses of resources by vehicle manufacturers to meet the proposed standards would enable the long-term reduction of national energy consumption and could enhance long-term national productivity. For further discussion of the costs and benefits of the proposed rule, consult NHTSA's Preliminary Regulatory Impact Analysis.

7.8 Irreversible and Irretrievable Commitments of Resources

As noted above, some HD vehicle manufacturers might need to commit additional resources to existing, redeveloped, or new production facilities to meet the Phase 2 fuel efficiency standards. In some cases, this could represent an irreversible and irretrievable commitment of resources. The specific amounts and types of irretrievable resources (such as electricity or other forms of energy) that manufacturers would expend in meeting the proposed standards would depend on the methods and technologies manufacturers select. However, the societal costs of the commitment of resources by manufacturers to comply with the proposed Phase 2 HD standards would most likely be offset by fuel savings generated from implementing the standards.

CHAPTER 8 MITIGATION

CEQ regulations implementing NEPA require that the discussion of alternatives in an EIS "[i]nclude appropriate mitigation measures not already included in the proposed action or alternatives" 40 CFR § 1502.14(f). An EIS should discuss the "[m]eans to mitigate adverse environmental impacts" 40 CFR § 1502.16(h). As defined in the CEQ regulations, mitigation includes the following (40 CFR § 1508.20):

- Avoiding the impact altogether by not taking a certain action or parts of an action.
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation.
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment.
- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.
- Compensating for the impact by replacing or providing substitute resources or environments.

Under NEPA, an agency does not have to formulate and adopt a complete mitigation plan[1] but should analyze possible measures that could be adopted. Generally, an agency does not propose mitigation measures for an action resulting in beneficial effects.

8.1 Overview of Impacts

Compared to Alternative 1 (No Action Alternative), each of the four action alternatives would reduce fuel consumption and greenhouse gas (GHG) emissions. As seen in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, the action alternatives would reduce the impacts of climate change that would otherwise occur under the No Action Alternative. According to the recent Fifth Assessment Report of the Intergovernmental Panel on Climate Change, substantial, sustained, and direct policy interventions around the world in the transportation sector can be consistent with long-term global CO_2 concentrations of 430 to 530 ppm. Moreover, a 15 to 40 percent reduction in global transportation-related CO_2 emissions by 2050 could be plausible compared to business as usual projections. However, there is limited evidence that reductions to date in carbon intensity, energy intensity, and activity have adequately constrained transportation sector GHG emissions growth in the context of mitigation targets. Stringent policy instruments and other incentives will be necessary to mitigate global increases in transportation emissions (IPCC 2014).

As reported in Chapter 4, *Air Quality*, emissions of criteria and hazardous air pollutants would decrease under all action alternatives and for all analysis years as compared to the No Action Alternative. Under the No Action Alternative, neither NHTSA nor EPA would issue a rule regarding HD vehicle fuel efficiency standards or GHG emissions for Phase 2 of the National Program. Compared to the No Action Alternative, health effects are estimated to be reduced and monetized health benefits would occur under all action alternatives for all analysis years (*see* Chapter 4, *Air Quality*). Although nationally all emissions are projected to decrease, some nonattainment areas within the United States could

[1] *Northern Alaska Environmental Center v. Kempthorne*, 457 F.3d 969, 979 (citing *Robertson v. Methow Valley Citizens Counsel*, 490 U.S. 332, 352 (1989) (noting that NEPA does not contain a substantive requirement that a complete mitigation plan be actually formulated and adopted)). *See* also *Valley Community Preservation Comm'n v. Mineta*, 231 F. Supp. 2d 23, 41 (D.D.C. 2002) (noting that NEPA does not require that a complete mitigation plan be formulated and incorporated into an EIS).

experience emissions increases for some pollutants under certain action alternatives and analysis years due to increases in vehicle miles traveled. These increases would represent a slight decline in the rate of reduction otherwise achieved by implementation of Clean Air Act (CAA) standards.

8.2 Mitigation Measures

NEPA does not obligate an agency to adopt a mitigation plan, but instead requires the agency to discuss possible measures that could be adopted. Because the action analyzed in this EIS has primarily been proposed to reduce the negative environmental consequences of fuel consumption and GHG emissions, and therefore comprises a type of mitigation measure in itself, the following discussion focuses on other federal actions that could also share the mitigation goals of the Proposed Action. These include current and future actions that NHTSA or other federal agencies could take to reduce increases in fuel consumption and GHG emissions in the transportation sector. As described in more detail below, many of these actions would provide even greater environmental benefits associated with the action alternatives. Although the measures described below are not being taken solely to address the impacts of the Proposed Action or action alternatives, NHTSA is describing them here because the actions could contribute to reducing adverse impacts or increasing net beneficial impacts of the Proposed Action and action alternatives.

As discussed above, some nonattainment areas could experience increases in some pollutant emissions as a result of implementation of the proposed standards. However, even if emissions in some nonattainment areas increase, the associated harm might not increase concomitantly. As described in Chapter 4, *Air Quality*, ambient levels of most pollutants are trending generally downward, owing to the success of regulations governing fuel composition and vehicle emissions, as well as stationary sources of emissions (EPA 2014a). Also, vehicle and trailer manufacturers can choose which technologies to employ to reach the new HD fuel efficiency requirements. Some of their technology choices could result in higher or lower impacts for these emissions.

Each action alternative would reduce energy consumption and GHG emissions compared to the No Action Alternative, resulting in a net beneficial effect. Nonetheless, HD vehicles are a major contributor to energy consumption, air pollution, and GHG emissions in the United States. The Federal Government is involved in a number of actions that, together with the Proposed Action, will help reduce GHG and other emissions from the U.S. transportation sector. The programs discussed below are ongoing and at various stages of completion. All of the programs present the potential for future developments and advances that could further increase the net beneficial effect of the environmental impacts identified in this EIS.

Federal funds administered by the Federal Highway Administration (FHWA) are available to help fund transportation projects to reduce emissions. FHWA provides funding to states and localities specifically to improve air quality under the Congestion Mitigation and Air Quality Improvement (CMAQ) Program. FHWA and the Federal Transit Administration (FTA) also provide funding to states and localities under other programs that have multiple objectives, including air quality improvement. For example, the Surface Transportation Program provides flexible funding that states could use for selected projects to reduce emissions (FHWA 2013). As state and local agencies conduct their review process and recognize the need to reduce emissions of CO, NO_x, particulate matter (PM) 2.5, acetaldehyde, acrolein, benzene, DPM, and formaldehyde (or other emissions eligible under the CMAQ Program, including the criteria pollutants and mobile source air toxics [MSATs] analyzed in this EIS), they can consider using CMAQ funds to help reduce these impacts.

Further, EPA has the authority to continue to improve vehicle emissions standards under the CAA, which could result in future reductions as EPA promulgates new regulations. Under the CAA, EPA also has the authority to regulate stationary sources of air pollution and GHG emissions (e.g., factories and utilities) (EPA 2014b). In addition, in a joint NHTSA and EPA rulemaking published in September 2011, NHTSA and EPA established the Phase 1 HD National Program to improve fuel efficiency and reduce GHG emissions of HD vehicles.[2] The agencies estimated that the Phase 1 HD National Program standards will save approximately 530 million barrels of oil and reduce GHG emissions by approximately 270 million metric tons over the life of MY 2014–2018 vehicles.[3]

Similarly, in October 2012, NHTSA and EPA issued a joint final rule that established CAFE and GHG emissions standards for MY 2017–2021 and MY 2017–2025 light-duty vehicle fleets, respectively.[4] This joint rulemaking is built on the May 2010 joint final rule in which NHTSA set CAFE standards and EPA set GHG emissions standards for MY 2012–2016 light-duty vehicles. The agencies estimate that the combination of these final standards will cut 6 billion metric tons of GHG emissions, save $1.7 trillion in fuel costs, and decrease the United States' dependence on oil by approximately 2 million barrels per day by 2025 (EPA 2014c). Final CAFE standards for MYs 2022–2025 will be established by NHTSA in a future rulemaking, based on the information available to the agency at that time.

EPA is also helping to reduce petroleum consumption and GHG emissions by implementing the Renewable Fuel Standards (RFS2) under CAA Section 211(o).[5] EPA is required to determine the standard applicable to refiners, importers, and certain blenders of gasoline annually. On the basis of this standard, each obligated party determines the volume of renewable fuel it must ensure is consumed as motor vehicle fuel. RFS2, which went into effect July 1, 2010, increases the volume of renewable fuel required to be blended into gasoline from a baseline of 9 billion gallons in 2008 to 36 billion gallons by 2022.[6] EPA estimates that the greater volume of biofuel mandated by RFS2 will reduce life-cycle GHG emissions by an annual average of 138 million tons of carbon dioxide equivalent (CO_2e) in 2022 (EPA 2010). The final renewable fuel standard for 2012 was 9.23 percent, and was increased in 2013 to 9.74 percent (EPA 2010, 2011).[7] As of November 2013, the proposed renewable fuel standard for 2014 was 9.20 percent (EPA 2013a). The percentage standard represents the ratio of renewable fuel volume to projected non-renewable gasoline and diesel volume. These proposed standards are intended to ensure "continued growth of renewable fuels while recognizing the practical limits on ethanol blending" (EPA 2013b).

EPA has also proposed standards of performance for allowable carbon emissions from new and existing power plants. In September 2013, EPA released a revised proposal that would cap emissions from new fossil fuel-fired electric utility generating units at 1,100 pounds of carbon dioxide (CO_2) per megawatt hour gross output over a 12-operating month period or 1,000 to 1,500 pounds of CO_2 per megawatt-

[2] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 76 FR 57106 (Sept. 15, 2011).
[3] *Id.*
[4] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule, 77 FR 62624 (Oct. 15, 2012).
[5] 2014 Standards for Renewable Fuel Standard Program; Proposed Rule, 78 FR 71732 (Nov. 29, 2013).
[6] Final Rule: Regulations of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. 75 FR 14670 (Mar. 26, 2010).
[7] Actual carbon savings might be less than anticipated because EIA projects that the actual volume of renewable fuels produced in 2022, 16 billion gallons, will fall short of the RFS target of 36 billion gallons (EIA AEO 2014).

hour of gross output over an 84-operating-month period.[8] For existing power plants, EPA proposed a rule in June 2014 requiring states to meet CO_2 emissions targets starting in 2020. The proposed rule is expected to reduce CO_2 emissions by 30 percent below 2005 levels by 2030. Both standards are expected to be finalized in 2015.

Another example of EPA's efforts to reduce fuel consumption is the agency's collaboration with the freight industry through the SmartWay Transport Partnership**Error! Bookmark not defined.**. Launched in 2004, the program provides incentives to the freight industry for improved supply-chain fuel efficiency through several components, including identification of available technologies and benchmarking. Since 2004, SmartWay Partners report saving 120.7 million barrels of oil and eliminating 51.6 million metric tons of CO_2 (EPA 2014d).

Further promoting efforts to reduce fuel consumption, the Federal Aviation Administration (FAA) is a sponsor of the Commercial Aviation Alternative Fuels Initiative (CAAFI), a coalition of the U.S. commercial aviation community that acts as a focal point for engaging the emerging alternative fuels industry (FAA 2009). The FAA is working to incorporate the use of sustainable "drop in" alternative jet fuels that can be used in current aircraft engines without modification by 2018 (FAA 2014). CAAFI seeks to enhance energy security by promoting the development of alternative fuel options for use in aviation, thereby potentially reducing impacts on GHG emissions in the transportation sector.

The U.S. Department of Energy (DOE) is also involved in a number of initiatives that aim to reduce fuel consumption. For example, DOE administers the Vehicle Technologies Program, which creates public-private partnerships that enhance energy efficiency and productivity and bring clean technologies to the marketplace with the potential to reduce GHG emissions (DOE 2014a). DOE received $35.2 billion under the American Recovery and Reinvestment Act of 2009, and has invested in a variety of projects including state energy efficiency programs, smart grid development, breakthrough technologies, and energy efficiency upgrades for homeowners (DOE 2013a). DOE also administers programs designed to give consumers and industries information required to make environmentally conscious decisions. Specifically, the DOE Clean Cities Program develops government-industry partnerships designed to reduce petroleum consumption "by advancing the use of alternative fuels and vehicles, idle reduction technologies, hybrid electric vehicles, fuel blends, and fuel economy measures" (DOE 2009). Through these developments, the Clean Cities Program has saved over 5 billion gallons of oil since the start of the program in 1993 (DOE 2013b). DOE also oversees the Appliance and Equipment Standards Program, created under the National Appliance Energy Conservation Act of 1986, which establishes minimum efficiency standards for many household appliances. Since its inception, the program has implemented standards for more than 50 products, which represent about 90 percent of home energy use, 60 percent of commercial building use, and 29 percent of industrial energy use. Annual CO_2 savings will reach over 275 million tons of CO_2 by 2020 and the program will have cumulatively avoided 6.8 billion tons by 2030 (DOE 2014b).

The U.S. DOE has also invested $115 million to fund the development of a Class 8 "SuperTruck," intended to increase fuel efficiency in HD vehicles through improvements in aerodynamics, advancing combustion techniques, recovery of waste heat to boost engine efficiency, and engine idling technologies. The SuperTruck's fuel economy has increased by 75 percent and GHG emissions have

[8] EPA. Standards of Performance for Greenhouse Gas Emissions from New Stationary Sources: Electric Utility Generating Units; Proposed Rule. Federal Register, Vol. 79, No. 5, January 8, 2014. http://www.gpo.gov/fdsys/pkg/FR-2014-01-08/pdf/2013-28668.pdf.

been reduced by 43 percent compared to the 2009 baseline truck (WSJ 2014). While only 4 percent of on-road vehicles are commercial trucks (class 8 vehicles included), they use 20 percent of the total fuel consumed and are responsible for transporting 80 percent of goods in the U.S. (DOE 2014c). DOE also launched the 21st Century Truck Partnership in 2000 to facilitate technology development for HD vehicles through research and development, collaboration, and information exchange. The partnership's goal is to help develop and introduce advanced technologies into the transportation industry so that trucks and buses can "safely and cost-effectively move larger volumes of freight and greater numbers of passengers while emitting little or no pollution and dramatically reducing the dependency on foreign oil" (21CTP 2013). The U.S. Department of Transportation (DOT) Federal Railroad Administration high-speed rail initiative intends to provide a travel alternative to reduce U.S. GHG emissions (FRA 2014). The overall strategy involves two parts: improving existing rail lines to make current train service faster and identifying potential corridors for the creation of high-speed rail. The American Recovery and Reinvestment Act of 2009 and annual appropriations have provided approximately $10 billion to expand the high-speed rail network in 33 states and the District of Columbia (SPRC 2011). DOT is also one of more than a dozen agency members of the U.S. Climate Change Technology Program, led by DOE, which aims to advance climate science, reduce GHG emissions, and promote international cooperation (DOE 2006, 2009). Additionally, DOE administers programs that provide mitigating effects, such as the Section 1605b Voluntary Reporting of Greenhouse Gases, which facilitates information sharing by providing a forum for recording strategies and reductions in GHGs (DOE 2002). Such programs can provide a source of information and strategy for future programs.

Government wide, Executive Order (EO) 13514 set measurable environmental performance goals for federal agencies and focused on making improvements in their environmental, energy, and economic performance. On January 29, 2010, President Obama announced that the Federal Government would reduce its GHG emissions from direct sources (e.g., lighting, heating, vehicle fuel, and federal projects) by 28 percent by 2020 (White House 2010a). This federal target was the aggregate of 35 federal agency self-reported targets. On July 20, 2010, this target was complemented by an additional target of 13 percent reduction in GHG emissions from indirect sources (e.g., employee travel and commuting) (White House 2010b). As part of this executive order, federal agencies were required to submit annual GHG emissions inventories. For fiscal year (FY) 2012, the Federal Government reported 60 million metric tons of CO_2e of GHG emissions subject to the reduction target, which is a reduction of 9 million metric tons of CO_2e from the FY 2008 baseline (DOE 2014d). In 2012, CEQ published an updated *Federal Greenhouse Gas Accounting and Reporting Guidance* providing agencies with revised "inventory reporting requirements and calculation methodologies" (CEQ 2012). The Federal Government is the single largest energy consumer in the U.S. economy, and the White House estimated that achieving the federal agency GHG emissions reduction targets would result in a cumulative reduction of 101 million metric tons of CO_2 emissions (White House 2010a).

On March 19, 2015, President Obama issued EO 13693, which sets additional environmental performance goals for federal agencies and focuses on reducing GHG emissions, improving environmental performance and federal sustainability, and increasing efficiency. EO 13693 promotes the use of clean energy (such as renewable electric energy), building and water use efficiency and management, and improved agency motor vehicle fleet efficiency and management.

8.3 Conclusion

Emissions of criteria and hazardous air pollutants are anticipated to decline under all action alternatives and for all analysis years as compared to the No Action Alternative. Energy consumption and GHG

emissions would also be reduced under all action alternatives as compared to the No Action Alternative. Several federal programs are in place to help increase the net beneficial impacts of the Proposed Action and alternatives. The initiatives and programs discussed in this chapter illustrate an existing and continuing trend of United States and global awareness, emphasis, and efforts toward reducing increases in energy consumption, GHG emissions, and other vehicle pollutants and mitigating their related environmental impacts.

CHAPTER 9 LIST OF PREPARERS AND REVIEWERS

9.1 U.S. Department of Transportation

Name/Role	Qualifications/Experience
PREPARERS	
James D. MacIsaac Jr., General Engineer, Contracting Officer's Representative, NHTSA	
	M.S., Engineering Management, George Washington University; B.S., Mechanical Engineering, Ohio State University
	15 years of experience in project management, research, and environmental analysis in support of federal motor vehicle safety and fuel economy standards
Megan Brown, Attorney Advisor, NHTSA	
	J.D., New York University School of Law; B.A., English and Plan II Honors, University of Texas at Austin
	2 years of legal experience, including environmental law
Coralie Cooper, Environmental Protection Specialist, Volpe Center	
	M.C.P., Environmental Policy and Planning, Massachusetts Institute of Technology; B.A., French Literature, Boston University
	19 years of experience in transportation policy, with a focus on state and federal policies to reduce transportation-related emissions and fuel consumption
Russell Krupen, Attorney Advisor, NHTSA	
	J.D., University of California, Los Angeles School of Law; B.A., Sociology, Harvard University
	4 years of legal experience, including environmental law
CONTRIBUTORS/REVIEWERS (alphabetically)	
John Donaldson, Assistant Chief Counsel, Legislation and General Law, NHTSA	
	J.D., Boston College Law School; B.A., Economics, Cornell University
	31 years of experience in vehicle safety issues, including environmental impact assessments
Kevin Green, Chief, CAFE Program Office, Volpe Center	
	M.Eng., Applied and Engineering Physics, Cornell University; B.S., Applied and Engineering Physics, Cornell University
	25 years of experience in transportation energy and emissions analysis and rulemaking; 14 years of experience in fuel economy rulemaking
Ryan Hagen, Attorney Advisor, NHTSA	
	J.D., Michigan State University College of Law; B.A., Journalism, Michigan State University
	2 years of legal experience

Name/Role	Qualifications/Experience
Kari Hicks, Honors Attorney, NHTSA	
	J.D., University of California, Los Angeles School of Law; B.A., English, University of California, Berkeley
	Less than 1 year of legal experience
Ryan Keefe, Operations Research Analyst, Volpe Center	
	Ph.D., Public Policy Analysis, Pardee RAND Graduate School, Santa Monica, CA; M.S., B.S., Mathematics (summa cum laude), University of Vermont–Burlington
	11 years of experience analyzing transportation, security, energy, and environmental policies
Analiese Marchesseault, Attorney Advisor, NHTSA	
	J.D., Brooklyn Law School; B.A., Art History, University of Chicago
	4 years of legal experience
Don H. Pickrell, Chief Economist, Volpe Center	
	Ph.D., Urban Planning; M.A., Urban Planning, University of California–Los Angeles; B.A. (with high honors), Economics and Mathematics, University of California–San Diego
	35 years of experience in applied transportation economics; 22 years of experience in analysis of environmental impacts of transportation activity
James Tamm, Chief, Fuel Economy Division, NHTSA	
	M.S., Mechanical Engineering, University of Michigan; B.S., Mechanical Engineering, Pennsylvania State University
	31 years of experience in automotive engineering related to fuel economy and emissions development; 5 years of experience in vehicle fuel economy rulemaking
O. Kevin Vincent, Chief Counsel, NHTSA	
	J.D., University of Alabama School of Law; B.S., Electrical Engineering, University of Alabama
	29 years of legal experience in contracts and administrative law issues

9.2 Consultant Team

ICF International supported the National Highway Traffic Safety Administration (NHTSA) in preparing its environmental analyses and this environmental impact statement (EIS).

Name/Role	Qualifications/Experience
PROJECT MANAGEMENT	
Elizabeth Diller, Project Manager	
	B.S., Environmental Science, University of Ulster at Coleraine, Northern Ireland
	14 years of experience in the environmental field and 12 years of experience in the management, preparation, and review of NEPA documents
Sarah Powers, Deputy Project Manager	
	J.D., Boston University School of Law; B.A., Astronomy and Physics, Boston University
	7 years of legal and regulatory experience; 2 years of experience in macroeconomic analysis
Richard Nevin, Senior Advisor, Energy Lead and Data Manager	
	M.B.A., Finance, Managerial Economics, and Strategy, Northwestern University; M.A., Economics, Boston University; B.A., Economics and Mathematics, Boston University
	33 years of experience managing and preparing environmental, energy, and economic analyses
Gretchen Pinkham, Project Coordinator and Air Quality Team	
	B.S. Environmental Studies, Keene State College
	4 years of experience in environmental assessment preparation, air quality analyses, and coal market analyses, including preparation of NEPA documents
TECHNICAL AND OTHER EXPERTISE (alphabetically)	
Bikash Acharya, Life-cycle Assessment and Climate Change Team	
	M.Eng., Mechanical Engineering, University of Maryland; B.S., Physics, Mathematical Economics, Applied Mathematics, Hampden Sydney College
	2 Years of experience in LCA, climate change and GHG emission estimation
Paul Bailey, Life-cycle Assessment Team	
	J.D., Harvard Law School; M.P.P., Kennedy School of Government, Harvard University; A.B., *summa cum laude,* Social Studies, Harvard College
	Over 35 years of experience in transportation, occupational safety, environmental accounting, life-cycle studies and policy analysis
Sarah Biggar, Life-cycle Assessment Team	
	B.S., Civil and Environmental Engineering, Bucknell University
	4 years of experience working with greenhouse gas accounting and inventories
Aaron Bishop, NEPA Analyst	
	B.A., Environmental Policy, The College of William and Mary
	1 year of experience in assisting in the construction and review of NEPA documents

Name/Role	Qualifications/Experience
Claire Boland, Life-cycle Assessment Team	
	B.S., Material Science and Engineering, Northwestern University; M.S., Sustainable Systems, University of Michigan
	2 years of experience in life-cycle assessments in regards to lightweighting vehicles
Gregory Carlock, Climate Change Team	
	M.P.P., Environmental Policy, University of Maryland; A.A.S., Intelligence Operations, Cochise College; B.S., Ecology, *magna cum laude,* Ohio State University
	5 years of experience specializing in clean energy, carbon accounting and project evaluation, federal energy and environmental reporting, and sustainability implementation
Casey Cavanagh, Air Quality Team	
	B.S., Geosciences/Geophysics, Virginia Polytechnic Institute and State University
	2 years of experience in exposure assessment and VBA programming
Michelle Cawley, Librarian/Technical Specialist	
	M.L.S., Library Science, North Carolina Central University; M.A., Ecology, University of North Carolina; B.A., Political Science, San Diego State University
	12 years of experience in consulting, education, and library settings
Brenda Dix, Climate Change Team	
	M.S., Civil Systems Engineering, University of California, Berkeley; B.S., Civil and Environmental Engineering, University of California, Berkeley
	6 years of experience working on projects involving greenhouse gas mitigation from the transportation sector, climate change vulnerability and adaptation assessments, and long range transportation planning
David Ernst, Air Quality Lead	
	M.C.R.P., Environmental Policy, Harvard University; B.S., Urban Systems Engineering; B.A., Ethics and Politics, Brown University
	34 years of experience preparing air quality analyses for NEPA documents
Ben Eskin, Life-cycle Assessment Team	
	B.A., Economics, Environmental Studies, cum laude, Macalester College
	2 years of experience supporting greenhouse gas inventory data collection and sustainability projects
Lizelle Espinosa, Reference Manager	
	B.S., Government Administration, Christopher Newport University
	9 years of experience in environmental consulting in the areas of environmental impact assessment, policy analysis, and regulatory compliance
Mark Flugge, Climate Change Team	
	Ph.D., Atmospheric Chemistry, University of Oxford; M.S., Chemistry, University of Oxford
	15 years of experience analyzing atmospheric chemistry, greenhouse gas, and climate change issues

Name/Role	Qualifications/Experience
Sara Forni, Life-cycle Assessment Team	
	B.S., Environmental Studies and Applications, Michigan State University
	3 years of experience in alternative fuel and advanced technology vehicle research and analysis for the National Renewable Energy Laboratory and other varied clients
Randall Freed, Senior Climate Change Advisor	
	M.S., Water Resource Management, University of Maryland; B.S., Zoology, University of Maryland
	40 years of experience in assessing and managing environmental risk; including 21 years of experience assessing climate change issues
Deborah Harris, Life-cycle Assessment Team	
	M.S.E., Environmental Engineering, Johns Hopkins University; B.S., Chemical Engineering, Carnegie Mellon University; B.S. Engineering and Public Policy, Carnegie Mellon University
	7 years of experience in conducting climate change and energy analyses
Christopher Holder, Air Quality Team	
	M.S., Meteorology, North Carolina State University; B.A., Meteorology, North Carolina State University
	6 years of experience in hazardous air pollutant risk assessment, climate change impacts, and greenhouse gas emission estimation
Kirsten Jaglo, Climate Change Team	
	Ph.D., Crop and Soil Science, Plant Breeding and Genetics, Michigan State University; B.A., Biology with a minor in Chemistry, *with honors*, University of Minnesota
	15 years of experience working with federal agencies, universities, Intergovernmental Organizations, and the private sector on scientific and policy issues related to climate change, water quality and agriculture
Adam Klauber, Life-cycle Assessment Co-lead	
	B.A., Political Science, Hobart College; M.P.A., Environmental Policy and Science, Columbia University
	11 years of experience in management, preparation of Federal transportation NEPA and policy documents
Tanvi Lal, Document Quality Control Lead	
	M.S., Environmental Science, M.P.A, Environmental Policy, School of Public and Environmental Affairs, Indiana University- Bloomington
	9 years of environmental consulting experience focused on the preparation, management, and review of NEPA documents
Jess Lam, Climate Change Team	
	M.E.M., Environmental Policy and Business, Duke University; B.S., Environmental Policy and Planning, University of California Davis
	2 years of experience in greenhouse gas emission sources and climate change
Grace Lange, Climate Change Team	
	B.A., International Studies, Dickinson College
	2 years of experience analyzing climate change impacts on local peoples

Name/Role	Qualifications/Experience
Alexander Lataille, Climate Change Team	
	B.S., Meteorology, Lyndon State College; B.A., Global Studies, Lyndon State College
	3 years of experience in climate change and sustainability consulting
Matthew Lichtash, Climate Change Team	
	B.S., Economics and Environmental Studies, Wesleyan University
	3 years of experience in researching climate literature related to climate mitigation
Deanna Lizas, Life-cycle Assessment Team	
	M.E.M., Environmental Management, Yale School of Forestry and Environmental Studies; B.S., Environmental Science and Sociology, University of Michigan
	11 years of experience in analysis of climate change issues and life-cycle energy and greenhouse gas emissions
Kristen Lundstrom, Editor	
	B.A., English Literature and Expository Writing, University of Washington; Certificate in Editing, University of Washington
	9 years of professional editing experience for various technical and environmental documents
Cory Matsui, Air Quality Specialist	
	B.A., Atmospheric Science, University of California, Berkeley
	4 years of experience preparing air quality analyses for CEQA and climate action plans for municipal governments in California
Derina Man, Climate Change Team	
	M.P.A., Environmental Science and Policy, Columbia University; B.Sc., Cell and Molecular Biology, McGill University; B.Ed. Secondary Education, McGill University
	3 years of experience analyzing climate change, greenhouse gas emissions and mitigation strategies, and ozone-depleting substance phase-out
Sarah Mello, NEPA Analyst and Air Quality Team	
	B.S. Integrated Science and Engineering, James Madison University
	1 year of experience in the preparation of NEPA documents
Matthew McFalls, Air Quality Team	
	M.S., Geography, San Diego State University; B.A., Public Administration and Urban Studies, San Diego State University
	6 years of experience analyzing air quality and greenhouse gas emission sources and impacts from public infrastructure and private development projects
Rawlings Miller, Climate Change Team, Section 5.4 and 5.5 Lead	
	Ph.D., Atmospheric Sciences, University of Arizona; M.S., Aerospace Engineering, Boston University; B.S., Physics, Union College
	18 years of experience with climate change modeling, air quality research, and impacts analysis; 9 years of consulting experience on environmental issues; 6 years of NEPA experience

Name/Role	Qualifications/Experience
Nikita Pavlenko, Life-cycle Assessment Team	
	B.A., Environmental Studies, Yale University
	3 years of experience in LCA, environmental impact studies, and analysis of greenhouse gas emissions from transportation and waste
Robert Renz, Life-cycle Assessment Co-lead	
	B.S., Mechanical Engineering, University of Virginia
	6 years of experience in LCA, environmental impact accounting, and preparation of Federal transportation NEPA and policy documents
Marybeth Riley-Gilbert, Climate Change Team	
	M.S., Atmospheric Science, Cornell University; B.S., Earth and Planetary Sciences, University of New Mexico
	9 years of experience in analysis of climate change impacts to water resources, terrestrial and marine ecosystems, transportation infrastructure, and human health
Michael J. Savonis, Reviewer	
	M.R.P., Cornell University 1985; B.S., Chemistry, State University of New York at Buffalo 1977
	28 years of experience in transportation policy; 17 years of experience in climate change mitigation, and impacts and adaptation assessment
Cassandra Snow, Climate Change Team	
	B.A., Environmental Science and Public Policy, *magna cum laude*, Harvard University
	4 years of experience in climate change and sustainability, specializing in climate change impacts and adaptation issues
Rebecca Shopiro, Climate Change Team	
	B.A., Environmental Studies, *magna cum laude*, Bucknell University
	2 years of experience supporting federal agencies with the phasedown of substances with high global warming potential (GWP) and analyzing options for reducing GHG emissions
Dana Spindler, Climate Change Team	
	M.A., Urban Planning, University of Washington; B.S., Environment and Natural Resources
	5 years of experience with climate change mitigation, vulnerabilities, and impacts
John Venezia, Climate Change Lead	
	M.S., Environmental Science and Policy, Johns Hopkins University; B.S., Biology and Environmental Science and Policy, Duke University
	16 years of experience analyzing climate change, greenhouse gas emission sources, and options for reducing emissions, focusing on the energy sector

Name/Role	Qualifications/Experience
Nicole Vetter, Librarian	
	M.L.S., Library Science, Simmons College, Boston, MA; B.A., Women's Studies, University of Minnesota, Minneapolis, MN
	6 years of library experience; 3 year consulting experience
Isaac Warren, Air Quality Team	
	B.A., Biology, with Distinction, Duke University
	4 years of experience in environmental risk and toxicology
Annah Peterson, NEPA Analyst, Energy Team	
	M.E.M., Environmental Economics and Policy, Duke University; B.A., Biology, Reed College
	6 years of experience in environmental consulting; 5 years of experience in NEPA

CHAPTER 10 DISTRIBUTION LIST

CEQ NEPA implementing regulations (40 CFR § 1501.19) specify requirements for circulating an EIS. In accordance with those requirements, NHTSA is mailing notification of the availability of this EIS as well as instructions on how to access it to the agencies, officials, and other stakeholders listed in this chapter.

10.1 Federal Agencies

- Access Board, Architectural and Transportation Barriers Compliance Board
- Advisory Council on Historic Preservation, Office of Federal Programs
- Alaska Natural Gas Transportation Projects, Office of the Federal Coordinator
- Appalachian Regional Commission
- Appalachian Regional Commission, Program Operations Division
- Appalachian Regional Commission, Regional Planning and Research
- Argonne National Laboratory
- Armed Forces Retirement Home
- Board of Governors of the Federal Reserve System, Engineering and Facilities
- Committee for Purchase From People Who Are Blind or Severely Disabled
- Consumer Product Safety Commission, Directorate for Economic Analysis
- Delaware River Basin Commission
- Denali Commission
- Department of Transportation, Federal Railroad Administration, Office of Policy and Development
- Executive Office of the President, Council on Environmental Quality
- Executive Office of the President, Office of Science and Technology Policy
- Export-Import Bank of the United States, Office of the General Counsel
- Farm Credit Administration, Office of Regulatory Policy
- Federal Communications Commission, Administrative Law Division
- Federal Communications Commission, Mass Media Bureau
- Federal Communications Commission, Office of General Counsel
- Federal Communications Commission, Wireless Telecommunications Bureau
- Federal Deposit Insurance Corporation, Cooperative Services
- Federal Energy Regulatory Commission
- Federal Energy Regulatory Commission, Division of Gas – Environment and Engineering
- Federal Energy Regulatory Commission, Division of Hydropower, Office of Energy Projects
- Federal Energy Regulatory Commission, Office of Energy Projects
- Federal Energy Regulatory Commission, Office of Pipeline Regulation
- Federal Maritime Commission
- Federal Trade Commission, Litigation
- General Services Administration
- General Services Administration, Public Buildings Service

- International Boundary and Water Commission, U.S. & Mexico, Environmental Management
- Marine Mammal Commission
- Millennium Challenge Corporation
- National Aeronautics and Space Administration, Environmental Management Division
- National Capital Planning Commission, Office of Urban Design and Plan Review
- National Credit Union Administration, Office of General Counsel, Division of Operations
- National Endowment for the Arts, General Counsel
- National Endowment for the Arts, Grants & Contracts
- National Indian Gaming Commission, Contracts Division
- National Science Foundation, Office of the General Counsel
- Nuclear Regulatory Commission, Division of Intergovernmental Liaison and Rulemaking
- Oak Ridge National Laboratory
- Office of Management and Budget
- Overseas Private Investment Corporation, Environmental Affairs Department
- Presidio Trust, NEPA Compliance
- Securities and Exchange Commission, Office of General Counsel
- Securities and Exchange Commission, Office of Support Operations
- Small Business Administration, Facilities Management Branch
- Small Business Administration, Office of Administration
- Small Business Administration, Office of the General Counsel, Department of Litigation & Claims
- Social Security Administration, Office of Environmental Health and Occupational Safety
- Susquehanna River Basin Commission
- Tennessee Valley Authority, Environmental Policy and Planning
- U.S. Department of Agriculture, Agriculture Research Service, Natural Resources and Sustainable Agricultural Systems
- U.S. Department of Agriculture, Animal and Plant Health Inspection Service – Environmental Services
- U.S. Department of Agriculture, Farm Service Agency
- U.S. Department of Agriculture, National Institute of Food and Agriculture – Natural Resources and Environmental Unit
- U.S. Department of Agriculture, Natural Resources Conservation Service – Ecological Services Division
- U.S. Department of Agriculture, Rural Housing Service / Rural Business Cooperative Service
- U.S. Department of Agriculture, Rural Utilities Service, Engineering and Environmental Staff
- U.S. Department of Agriculture, U.S. Forest Service – Ecosystem Management Coordination
- U.S. Department of Commerce, Economic Development Administration
- U.S. Department of Commerce, Gulf Coast Ecosystem Restoration Council
- U.S. Department of Commerce, National Marine Fisheries Service
- U.S. Department of Commerce, National Oceanic and Atmospheric Administration
- U.S. Department of Commerce, National Telecommunications and Information Administration
- U.S. Department of Commerce, NOAA National Marine Fisheries Service

- U.S. Department of Commerce, NOAA National Ocean Service
- U.S. Department of Defense, Army Corps of Engineers – Civil Works
- U.S. Department of Defense, Army Corps of Engineers Headquarters
- U.S. Department of Defense, Army Corps of Engineers, Planning and Policy Division
- U.S. Department of Defense, Defense Logistics Agency; Environment, Safety and Occupational Health
- U.S. Department of Defense, Defense Threat Reduction Agency
- U.S. Department of Defense, Department of Air Force, U.S. Air Force Basing and Units
- U.S. Department of Defense, Department of Army, Office of the Assistant Secretary of the Army, Installations & Environment
- U.S. Department of Defense, Department of Navy, Office of the Deputy Assistant Secretary of the Navy (Environment)
- U.S. Department of Defense, Joint Guam Program Office
- U.S. Department of Defense, National Guard Bureau
- U.S. Department of Defense, National Guard Bureau, Office of the Chief Counsel
- U.S. Department of Defense, Navy Installations Command
- U.S. Department of Defense, Office of Deputy Undersecretary Defense (Installations and Environment)
- U.S. Department of Defense, Office of the Assistance Chief of Staff for Installations
- U.S. Department of Defense, Office of the Chief of Naval Operations (CNO-N45)
- U.S. Department of Defense, United States Marine Corps, Natural and Cultural Resources Division
- U.S. Department of Education
- U.S. Department of Energy, Bonneville Power Administration
- U.S. Department of Energy, Office of the General Counsel – Office of NEPA Policy and Compliance
- U.S. Department of Energy, Western Area Power Administration
- U.S. Department of Health and Human Services, Center for Tobacco Products, Toxicology and Environmental Science
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention – National Center for Environmental Health
- U.S. Department of Health and Human Services, FDA Center for Drug Evaluation and Research
- U.S. Department of Health and Human Services, FDA Center for Food Safety and Applied Nutrition
- U.S. Department of Health and Human Services, FDA Center for Veterinary Medicine – Office of New Animal Drug Evaluation
- U.S. Department of Health and Human Services, Food and Drug Administration – Office of the Commissioner
- U.S. Department of Health and Human Services, Health Resources Services Administration, Office of Federal Assistance Management
- U.S. Department of Health and Human Services, Indian Health Service
- U.S. Department of Health and Human Services, National Institutes of Health
- U.S. Department of Health and Human Services, National Institutes of Health, Division of Environmental Protection

- U.S. Department of Health and Human Services, Office for Facilities Management and Policy – Division of Programs
- U.S. Department of Homeland Security
- U.S. Department of Homeland Security, Federal Emergency Management Agency – Office of Environmental Planning and Historic Preservation
- U.S. Department of Homeland Security, Federal Law Enforcement Training Center
- U.S. Department of Homeland Security, Transportation Security Administration
- U.S. Department of Homeland Security, U.S. Coast Guard
- U.S. Department of Homeland Security, U.S. Customs and Border Protection
- U.S. Department of Homeland Security, Immigration and Customs Enforcement
- U.S. Department of Homeland Security, U.S. Citizen and Immigration Services, Facilities Management Division
- U.S. Department of Homeland Security, U.S. Customs and Border Protection
- U.S. Department of Housing and Urban Development, Office of Environment and Energy
- U.S. Department of Interior, Bureau of Indian Affairs
- U.S. Department of Interior, Bureau of Land Management, Division of Decision Support, Planning, and NEPA
- U.S. Department of Interior, Bureau of Ocean Energy Management
- U.S. Department of Interior, Bureau of Reclamation, Water & Environmental Resources Office
- U.S. Department of Interior, National Park Service – Environmental Planning and Compliance Branch
- U.S. Department of Interior, Office of Environmental Policy and Compliance
- U.S. Department of Interior, Office of Surface Mining
- U.S. Department of Interior, U.S. Fish and Wildlife Service
- U.S. Department of Interior, U.S. Geological Survey – Environmental Management Branch
- U.S. Department of Interior, Bureau of Safety and Environmental Enforcement
- U.S. Department of Interior, National Park Service, Environmental Quality Division
- U.S. Department of Interior, Office of Environmental Affairs, Natural Resources Management
- U.S. Department of Justice, Community Oriented Policing Services, Office of General Counsel
- U.S. Department of Justice, Drug Enforcement Administration, Civil Litigation Section
- U.S. Department of Justice, Environment and Natural Resources Division
- U.S. Department of Justice, Facilities and Administration Services
- U.S. Department of Justice, Federal Bureau of Investigation
- U.S. Department of Justice, Federal Bureau of Prisons, Site Selection and Environmental Review Branch
- U.S. Department of Justice, Justice Management Division
- U.S. Department of Justice, National Institute of Justice
- U.S. Department of Justice, Office of Justice Programs, Office of General Counsel
- U.S. Department of Justice, U.S. Marshals Service, Office of General Counsel
- U.S. Department of Labor, Employment and Training Administration, Job Corps
- U.S. Department of Labor, Mine Safety and Health Administration, Office of Standards, Regulations and Variances

- U.S. Department of Labor, Occupational Safety and Health Administration, Office of Regulatory Analysis
- U.S. Department of Labor, Office of the Assistant Secretary for Policy
- U.S. Department of State, Bureau of Oceans and International Environmental and Scientific Affairs
- U.S. Department of State, Bureau of Oceans and International Environmental and Scientific Affairs, Office of Multilateral Affairs and Sustainable Development
- U.S. Department of State, OES/EQT
- U.S. Department of the Treasury, Office of Environment, Safety, and Health
- U.S. Department of Transportation
- U.S. Department of Transportation, Federal Highway Administration, Office of Project Development and Environmental Review
- U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Office of the Chief Counsel
- U.S. Department of Transportation, Federal Railroad Administration, Office of Railroad Development
- U.S. Department of Transportation, Federal Transit Administration, Office of Planning and Environment
- U.S. Department of Transportation, Saint Lawrence Seaway Development Corporation
- U.S. Department of Transportation, Surface Transportation Board, Office of Environmental Analysis
- U.S. Department of Transportation, Federal Aviation Administration
- U.S. Department of Transportation, Federal Highway Administration
- U.S. Department of Transportation, Federal Transit Administration, Office of Human and Natural Environment
- U.S. Department of Transportation, Maritime Administration
- U.S. Department of Transportation, Office of Assistant Secretary for Transportation Policy
- U.S. Department of Transportation, Office of General Counsel
- U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration
- U.S. Department of Transportation, Volpe Center
- U.S. Department of Treasury, CDFI Fund, Office of Legal Counsel
- U.S. Department of Veterans Affairs, Veterans Health Administration, Office of General Counsel
- U.S. Department of Veterans Affairs, Veterans Health Administration
- U.S. Environmental Protection Agency
- U.S. Institute for Environmental Conflict Resolution
- United States Agency for International Development
- United States Postal Service
- Valles Caldera Trust

10.2 State and Local Government Organizations

- American Samoa Office of Grants Policy/Office of the Governor, Department of Commerce American Samoa Government
- Arkansas Office of Intergovernmental Services, Department of Finance and Administration
- Connecticut Department of Environmental Protection

- Delaware Office of Management and Budget, Budget Development, Planning & Administration
- District of Columbia Office of the City Administrator
- Federal Assistance Clearinghouse, Missouri Office of Administration, Commissioner's Office
- Florida State Clearinghouse, Florida Dept. of Environmental Protection
- Georgia State Clearinghouse
- Grants Coordination, California State Clearinghouse, Office of Planning and Research
- Guam State Clearinghouse, Office of I Segundo na Maga'lahen Guahan, Office of the Governor
- Iowa Department of Management
- Maine State Planning Office
- Maryland Department of Planning
- Maryland Department of Transportation
- Maryland State Clearinghouse for Intergovernmental Assistance
- Massachusetts Office of the Attorney General
- Minnesota Department of Commerce, Division of Energy Resources
- Minnesota Department of Environmental Protection
- Nevada Division of State Lands
- New Hampshire Office of Energy and Planning, Attn: Intergovernmental Review Process
- North Dakota Department of Commerce
- Pennsylvania Department of Environmental Protection
- Puerto Rico Highway and Transportation Authority
- Puerto Rico Planning Board, Federal Proposals Review Office
- Rhode Island Division of Planning
- Saint Thomas, VI Office of Management and Budget
- South Carolina Office of State Budget
- Southeast Michigan Council of Governments
- The Governor of Kentucky's Office for Local Development
- Utah State Clearinghouse, Governor's Office of Planning and Budget Utah State
- West Virginia Development Office

10.3 Elected Officials

- The Honorable Robert Bentley, Governor of Alabama
- The Honorable Bill Walker, Governor of Alaska
- The Honorable Lolo Matalasi Moliga, Governor of American Samoa
- The Honorable Doug Ducey, Governor of Arizona
- The Honorable Asa Hutchinson, Governor of Arkansas
- The Honorable Edmund G. Brown, Governor of California
- The Honorable John Hickenlooper, Governor of Colorado
- The Honorable Dannel Malloy, Governor of Connecticut
- The Honorable Jack Markell, Governor of Delaware

- The Honorable Rick Scott, Governor of Florida
- The Honorable Nathan Deal, Governor of Georgia
- The Honorable Eddie Calvo, Governor of Guam
- The Honorable David Ige, Governor of Hawaii
- The Honorable C.L. "Butch" Otter, Governor of Idaho
- The Honorable Bruce Rauner, Governor of Illinois
- The Honorable Mike Pence, Governor of Indiana
- The Honorable Terry Branstad, Governor of Iowa
- The Honorable Sam Brownback, Governor of Kansas
- The Honorable Steve Beshear, Governor of Kentucky
- The Honorable Bobby Jindal, Governor of Louisiana
- The Honorable Paul LePage, Governor of Maine
- The Honorable Larry Hogan, Governor of Maryland
- The Honorable Charles Baker, Governor of Massachusetts
- The Honorable Rick Snyder, Governor of Michigan
- The Honorable Mark Dayton, Governor of Minnesota
- The Honorable Phil Bryant, Governor of Mississippi
- The Honorable Jeremiah (Jay) Nixon, Governor of Missouri
- The Honorable Steve Bullock, Governor of Montana
- The Honorable Pete Ricketts, Governor of Nebraska
- The Honorable Brian Sandoval, Governor of Nevada
- The Honorable Maggie Hassan, Governor of New Hampshire
- The Honorable Chris Christie, Governor of New Jersey
- The Honorable Susana Martinez, Governor of New Mexico
- The Honorable Andrew Cuomo, Governor of New York
- The Honorable Pat McCrory, Governor of North Carolina
- The Honorable Jack Dalrymple, Governor of North Dakota
- The Honorable Eloy S. Inos, Governor of the Commonwealth of the Northern Mariana IslandsThe Honorable John Kasich, Governor of Ohio
- The Honorable Mary Fallin, Governor of Oklahoma
- The Honorable Kate Brown, Governor of Oregon
- The Honorable Tom Wolf, Governor of Pennsylvania
- The Honorable Alejandro García Padilla, Governor of Puerto Rico
- The Honorable Gina Raimondo, Governor of Rhode Island
- The Honorable Nikki R. Haley, Governor of South Carolina
- The Honorable Dennis Daugaard, Governor of South Dakota
- The Honorable Bill Haslam, Governor of Tennessee
- The Honorable Greg Abbott, Governor of TexasThe Honorable Kenneth Mapp, Governor of the United States Virgin Islands
- The Honorable Gary Herbert, Governor of Utah

- The Honorable Peter Shumlin, Governor of Vermont
- The Honorable Terry McAuliffe, Governor of Virginia
- The Honorable Jay Inslee, Governor of Washington
- The Honorable Earl Ray Tomblin, Governor of West Virginia
- The Honorable Scott Walker, Governor of Wisconsin
- The Honorable Matthew Mead, Governor of Wyoming
- The Honorable Muriel Bowser, Mayor of the District of Columbia

10.4 Federally Recognized Native American Tribes

- Absentee-Shawnee Tribe of Indians of Oklahoma
- Agdaagux Tribe of King Cove
- Agua Caliente Band of Cahuilla Indians of the Agua Caliente Indian Reservation
- Ak Chin Indian Community of the Maricopa (Akchin) Indian Reservation
- Akiachak Native Community
- Akiak Native Community
- Alabama-Coushatta Tribe of Texas
- Alabama-Quassarte Tribal Town
- Alatna Village
- Algaaciq Native Village (St. Mary's)
- Allakaket Village
- Alturas Indian Rancheria
- Angoon Community Association
- Anvik Village
- Apache Tribe of Oklahoma
- Arapaho Tribe of the Wind River Reservation
- Arctic Village
- Aroostook Band of Micmacs
- Asa'carsarmiut Tribe
- Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation
- Atqasuk Village (Atkasook)
- Augustine Band of Cahuilla Indians
- Bad River Band of Lake Superior Tribe of Chippewa Indians of the Bad River Reservation
- Battle Mountain Band (Te-Moak Tribe of Western Shoshone Indians of Nevada)
- Bay Mills Indian Community
- Bear River Band of the Rohnerville Rancheria
- Beaver Village
- Berry Creek Rancheria of Maidu Indians of California
- Big Lagoon Rancheria
- Big Pine Paiute Tribe of the Owens Valley

- Big Sandy Rancheria of Western Mono Indians of California
- Big Valley Band of Pomo Indians of the Big Valley Rancheria
- Birch Creek Tribe
- Bishop Paiute Tribe
- Blackfeet Tribe of the Blackfeet Indian Reservation of Montana
- Blue Lake Rancheria
- Bridgeport Indian Colony
- Buena Vista Rancheria of Me-Wuk Indians of California
- Burns Paiute Tribe
- Cabazon Band of Mission Indians
- Cachil DeHe Band of Wintun Indians of the Colusa Indian Community of the Colusa Rancheria
- Caddo Nation of Oklahoma
- Cahto Tribe of the Laytonville Rancheria
- Cahuilla Band of Mission Indians of the Cahuilla Reservation
- California Valley Miwok Tribe
- Campo Band of Diegueno Mission Indians of the Campo Indian Reservation
- Capitan Grande Band of Diegueno Mission Indians of California
- Capitan Grande Band of Diegueno Mission Indians of California
- Carson Colony
- Catawba Indian Nation
- Cayuga Nation
- Cedarville Rancheria
- Central Council of the Tlingit & Haida Indian Tribes
- Chalkyitsik Village
- Cheesh-Na Tribe
- Chemehuevi Indian Tribe of the Chemehuevi Reservation
- Cher-Ae Heights Indian Community of the Trinidad Rancheria
- Cherokee Nation
- Chevak Native Village
- Cheyenne and Arapaho Tribes
- Cheyenne River Sioux Tribe of the Cheyenne River Reservation
- Chickaloon Native Village
- Chicken Ranch Rancheria of Me-Wuk Indians of California
- Chignik Bay Tribal Council
- Chignik Lake Village
- Chilkat Indian Village (Klukwan)
- Chilkoot Indian Association (Haines)
- Chinik Eskimo Community (Golovin)
- Chippewa-Cree Indians of the Rocky Boy's Reservation

- Chitimacha Tribe of Louisiana
- Chuloonawick Native Village
- Circle Native Community
- Citizen Potawatomi Nation
- Cloverdale Rancheria of Pomo Indians of California
- Cocopah Tribe of Arizona
- Coeur D'Alene Tribe
- Cold Springs Rancheria of Mono Indians of California
- Colorado River Indian Tribes of the Colorado River Indian Reservation
- Comanche Nation
- Confederated Salish Kootenai Tribes of the Flathead Reservation
- Confederated Tribes and Bands of the Yakama Nation
- Confederated Tribes of Siletz Indians of Oregon
- Confederated Tribes of the Chehalis Reservation
- Confederated Tribes of the Colville Reservation
- Confederated Tribes of the Coos, Lower Umpqua and Siuslaw Indians
- Confederated Tribes of the Goshute Reservation
- Confederated Tribes of the Grand Ronde Community of Oregon
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of the Warm Springs Reservation of Oregon
- Coquille Indian Tribe
- Cortina Indian Rancheria of Wintun Indians of California
- Coushatta Tribe of Louisiana
- Cow Creek Band of Umpqua Tribe of Indians
- Cowlitz Indian Tribe
- Coyote Valley Band of Pomo Indians of California
- Craig Tribal Association
- Crow Creek Sioux Tribe of the Crow Creek Reservation
- Crow Tribe of Montana
- Curyung Tribal Council
- Death Valley Timbi-sha Shoshone Tribe
- Delaware Nation
- Delaware Tribe of Indians
- Douglas Indian Association
- Dresslerville Colony
- Dry Creek Rancheria Band of Pomo Indians
- Duckwater Shoshone Tribe of the Duckwater Reservation
- Eastern Band of Cherokee Indians
- Eastern Shawnee Tribe of Oklahoma

- Egegik Village
- Eklutna Native Village
- Elem Indian Colony of Pomo Indians of the Sulphur Bank Rancheria
- Elk Valley Rancheria
- Elko Band
- Ely Shoshone Tribe of Nevada
- Emmonak Village
- Enterprise Rancheria of Maidu Indians of California
- Evansville Village
- Ewiiaapaayp Band of Kumeyaay Indians
- Federated Indians of Graton Rancheria
- Flandreau Santee Sioux Tribe of South Dakota
- Forest County Potawatomi Community
- Fort Belknap Indian Community of the Fort Belknap Reservation of Montana
- Fort Bidwell Indian Community of the Fort Bidwell Reservation of California
- Fort Independence Indian Community of Paiute Indians of the Fort Independence Reservation
- Fort McDermitt Paiute and Shoshone Tribes of the Fort McDermitt Indian Reservation
- Fort McDowell Yavapai Nation
- Fort Mojave Indian Tribe of Arizona, California & Nevada
- Fort Sill Apache Tribe of Oklahoma
- Galena Village
- Gila River Indian Community of the Gila River Indian Reservation
- Grand Traverse Band of Ottawa & Chippewa Indians
- Greenville Rancheria
- Grindstone Indian Rancheria of Wintun-Wailaki Indians of California
- Guidiville Rancheria of California
- Gulkana Village
- Habematolel Pomo of Upper Lake
- Hannahville Indian Community
- Havasupai Tribe of the Havasupi Reservation
- Healy Lake Village
- Ho-Chunk Nation of Wisconsin
- Hoh Indian Tribe
- Holy Cross Village
- Hoonah Indian Association
- Hoopa Valley Tribe
- Hopi Tribe of Arizona
- Hopland Band of Pomo Indians
- Houlton Band of Maliseet Indians

- Hualapai Indian Tribe of the Hualapai Indian Reservation
- Hughes Village
- Huslia Village
- Hydaburg Cooperative Association
- Igiugig Village
- Iipay Nation of Santa Ysabel
- Inaja Band of Diegueno Mission Indians of the Inaja and Cosmit Reservation
- Indians of the Lac du Flambeau Reservation of Wisconsin
- Inupiat Community of the Arctic Slope
- Ione Band of Miwok Indians of California
- Iowa Tribe of Kansas and Nebraska
- Iowa Tribe of Oklahoma
- Iqurmiut Traditonal Council
- Ivanoff Bay Village
- Jackson Rancheria of Me-Wuk Indians of California
- Jamestown S'Klallam Tribe
- Jamul Indian Village of California
- Jena Band of Choctaw Indians
- Jicarilla Apache Nation
- Kaguyak Village
- Kaibab Band of Paiute Indians of the Kaibab Indian Reservation
- Kaktovik Village
- Kalispel Indian Community of the Kalispel Reservation
- Karuk Tribe
- Kashia Band of Pomo Indians of the Stewarts Point Rancheria
- Kasigluk Traditional Elders Council
- Kaw Nation
- Kenaitze Indian Tribe
- Ketchikan Indian Corporation
- Kewa Pueblo
- Keweenaw Bay Indian Community
- Kialegee Tribal Town
- Kickapoo Traditional Tribe of Texas
- Kickapoo Tribe of Indians of the Kickapoo Reservation in Kansas
- Kickapoo Tribe of Oklahoma
- King Island Native Community
- King Salmon Tribe
- Kiowa Indian Tribe of Oklahoma
- Klamath Tribes

- Klawock Cooperative Association
- Knik Tribe
- Koi Nation of Northern California
- Kokhanok Village
- Kootenai Tribe of Idaho
- Koyukuk Native Village
- La Jolla Band of Luiseno Indians
- La Posta Band of Diegueno Mission Indians of the La Posta Indian Reservation
- Lac Courte Oreilles Band of Lake Superior Chippewa Indians of Wisconsin
- Lac du Flambeau Band of Lake Superior Chippewa
- Lac Vieux Desert Band of Lake Superior Chippewa Indians of Michigan
- Las Vegas Tribe of Paiute Indians of the Las Vegas Indian Colony
- Levelock Village
- Lime Village
- Little River Band of Ottawa Indians
- Little Traverse Bay Bands of Odawa Indians
- Lone Pine Paiute-Shoshone Tribe
- Los Coyotes Band of Cahuilla and Cupeno Indians
- Lovelock Paiute Tribe of the Lovelock Indian Colony
- Lower Brule Sioux Tribe of the Lower Brule Reservation
- Lower Elwha Tribal Community
- Lower Sioux Indian Community in the State of Minnesota
- Lummi Tribe of the Lummi Reservation
- Lytton Rancheria of California
- Makah Indian Tribe of the Makah Indian Reservation
- Manchester Band of Pomo Indians of the Manchester Rancheria
- Manley Hot Springs Village
- Manokotak Village
- Manzanita Band of Diegueno Mission Indians of the Manzanita Reservation
- Mashantucket Pequot Indian Tribe
- Mashpee Wampanoag Indian Tribal Council, Inc.
- Match-e-be-nash-she-wish Band of Pottawatomi Indians of Michigan
- McGrath Native Village
- Mechoopda Indian Tribe of Chico Rancheria
- Menominee Indian Tribe of Wisconsin
- Mentasta Traditional Council
- Mesa Grande Band of Diegueno Mission Indians of the Mesa Grande Reservation
- Mescalero Apache Tribe of the Mescalero Reservation
- Metlakatla Indian Community, Annette Island Reserve

- Miami Tribe of Oklahoma
- Miccosukee Tribe of Indians
- Middletown Rancheria of Pomo Indians of California
- Minnesota Chippewa Tribe
- Minnesota Chippewa Tribe – Bois Forte Band (Nett Lake)
- Minnesota Chippewa Tribe – Fond du Lac Band
- Minnesota Chippewa Tribe – Grand Portage Band
- Minnesota Chippewa Tribe – Leech Lake Band
- Minnesota Chippewa Tribe – Mille Lacs Band
- Minnesota Chippewa Tribe – White Earth Band
- Mississippi Band of Choctaw Indians
- Moapa Band of Paiute Indians of the Moapa River Indian Reservation
- Mohegan Tribe of Indians of Connecticut
- Mooretown Rancheria of Maidu Indians of California
- Morongo Band of Mission Indians
- Muckleshoot Indian Tribe
- Naknek Native Village
- Narragansett Indian Tribe
- Native Village of Afognak
- Native Village of Akhiok
- Native Village of Akutan
- Native Village of Aleknagik
- Native Village of Ambler
- Native Village of Atka
- Native Village of Barrow Inupiat Traditional Government
- Native Village of Belkofski
- Native Village of Brevig Mission
- Native Village of Buckland
- Native Village of Cantwell
- Native Village of Chenega
- Native Village of Chignik Lagoon
- Native Village of Chitina
- Native Village of Chuathbaluk (Russian Mission, Kuskokwim)
- Native Village of Council
- Native Village of Deering
- Native Village of Diomede
- Native Village of Eagle
- Native Village of Eek
- Native Village of Ekuk

- Native Village of Ekwok
- Native Village of Elim
- Native Village of Eyak (Cordova)
- Native Village of False Pass
- Native Village of Fort Yukon
- Native Village of Gakona
- Native Village of Gambell
- Native Village of Georgetown
- Native Village of Goodnews Bay
- Native Village of Hamilton
- Native Village of Hooper Bay
- Native Village of Kanatak
- Native Village of Karluk
- Native Village of Kiana
- Native Village of Kipnuk
- Native Village of Kivalina
- Native Village of Kluti Kaah
- Native Village of Kobuk
- Native Village of Kongiganak
- Native Village of Kotzebue
- Native Village of Koyuk
- Native Village of Kwigillingok
- Native Village of Kwinhagak
- Native Village of Larsen Bay
- Native Village of Marshall
- Native Village of Mary's Igloo
- Native Village of Mekoryuk
- Native Village of Minto
- Native Village of Nanwalek
- Native Village of Napaimute
- Native Village of Napakiak
- Native Village of Napaskiak
- Native Village of Nelson Lagoon
- Native Village of Nightmute
- Native Village of Nikolski
- Native Village of Noatak
- Native Village of Nuiqsut
- Native Village of Nunam Iqua
- Native Village of Nunapitchuk

- Native Village of Old Harbor
- Native Village of Ouzinkie
- Native Village of Paimiut
- Native Village of Perryville
- Native Village of Pilot Point
- Native Village of Pitka's Point
- Native Village of Point Hope
- Native Village of Point Lay
- Native Village of Port Graham
- Native Village of Port Heiden
- Native Village of Port Lions
- Native Village of Ruby
- Native Village of Saint Michael
- Native Village of Savoonga
- Native Village of Scammon Bay
- Native Village of Selawik
- Native Village of Shaktoolik
- Native Village of Shishmaref
- Native Village of Shungnak
- Native Village of Stevens
- Native Village of Tanacross
- Native Village of Tanana
- Native Village of Tatitlek
- Native Village of Tazlina
- Native Village of Teller
- Native Village of Tetlin
- Native Village of Tuntutuliak
- Native Village of Tununak
- Native Village of Tyonek
- Native Village of Unalakleet
- Native Village of Unga
- Native Village of Venetie Tribal Government
- Native Village of Wales
- Native Village of White Mountain
- Navajo Nation
- Nenana Native Association
- New Koliganek Village Council
- New Stuyahok Village
- Newhalen Village

- Newtok Village
- Nez Perce Tribe
- Nikolai Village
- Ninilchik Village
- Nisqually Indian Tribe
- Nome Eskimo Community
- Nondalton Village
- Nooksack Indian Tribe
- Noorvik Native Community
- Northern Cheyenne Tribe
- Northfork Rancheria of Mono Indians of California
- Northway Village
- Northwestern Band of Shoshoni Nation
- Nottawaseppi Huron Band of the Potawatomi
- Nulato Village
- Nunakauyarmiut Tribe
- Oglala Sioux Tribe
- Ohkay Owingeh
- Omaha Tribe of Nebraska
- Oneida Nation of New York
- Oneida Tribe of Indians of Wisconsin
- Onondaga Nation
- Organized Village of Grayling
- Organized Village of Kake
- Organized Village of Kasaan
- Organized Village of Kwethluk
- Organized Village of Saxman
- Orutsararmuit Native Village
- Oscarville Traditional Village
- Otoe-Missouria Tribe of Indians
- Ottawa Tribe of Oklahoma
- Paiute Indian Tribe of Utah
- Paiute-Shoshone Tribe of the Fallon Reservation and Colony
- Pala Band of Luiseno Mission Indians of the Pala Reservation
- Pascua Yaqui Tribe of Arizona
- Paskenta Band of Nomlaki Indians of California
- Passamaquoddy Tribe – Indian Township
- Passamaquoddy Tribe – Pleasant Point
- Pauloff Harbor Village

- Pauma Band of Luiseno Mission Indians
- Pawnee Nation of Oklahoma
- Pechanga Band of Luiseno Mission Indians
- Pedro Bay Village
- Penobscot Nation
- Peoria Tribe of Indians of Oklahoma
- Petersburg Indian Association
- Picayune Rancheria of Chukchansi Indians of California
- Pilot Station Traditional Village
- Pinoleville Pomo Nation
- Pit River Tribe
- Platinum Traditional Village
- Poarch Band of Creeks
- Pokagon Band of Potawatomi Indians
- Ponca Tribe of Indians of Oklahoma
- Ponca Tribe of Nebraska
- Port Gamble S'Klallam Tribe
- Portage Creek Village
- Potter Valley Tribe
- Prairie Band Potawatomi Nation
- Prairie Island Indian Community in the State of Minnesota
- Pueblo of Acoma
- Pueblo of Cochiti
- Pueblo of Isleta
- Pueblo of Jemez
- Pueblo of Laguna
- Pueblo of Nambe
- Pueblo of Picuris
- Pueblo of Pojoaque
- Pueblo of San Felipe
- Pueblo of San Ildefonso
- Pueblo of Sandia
- Pueblo of Santa Ana
- Pueblo of Santa Clara
- Pueblo of Taos
- Pueblo of Tesuque
- Pueblo of Zia
- Puyallup Tribe of the Puyallup Reservation
- Pyramid Lake Paiute Tribe of the Pyramid Lake Reservation

- Qagan Tayagungin Tribe of Sand Point Village
- Qawalangin Tribe of Unalaska
- Quartz Valley Indian Community of the Quartz Valley Reservation of California
- Quechan Tribe of the Fort Yuma Indian Reservation
- Quileute Tribe of the Quileute Reservation
- Quinault Indian Nation
- Ramah Navajo Chapter, Navajo Nation
- Ramona Band of Cahuilla
- Rampart Village
- Red Cliff Band of Lake Superior Chippewa Indians of Wisconsin
- Red Lake Band of Chippewa Indians
- Redding Rancheria
- Redwood Valley or Little River Band of Pomo Indians of the Redwood Valley Rancheria California
- Reno-Sparks Indian Colony
- Resighini Rancheria
- Rincon Band of Luiseno Mission Indians of the Rincon Reservation
- Robinson Rancheria Band of Pomo Indians
- Rosebud Sioux Tribe of the Rosebud Indian Reservation
- Round Valley Indian Tribes, Round Valley Reservation
- Sac & Fox Nation of Missouri in Kansas and Nebraska
- Sac & Fox Nation, Oklahoma
- Sac & Fox Tribe of the Mississippi in Iowa
- Saginaw Chippewa Indian Tribe of Michigan
- Saint George Island
- Saint Paul Island
- Saint Regis Mohawk Tribe
- Salt River Pima-Maricopa Indian Community of the Salt River Reservation
- Samish Indian Nation
- San Carlos Apache Tribe of the San Carlos Reservation
- San Juan Southern Paiute Tribe of Arizona
- San Manuel Band of Mission Indians
- San Pasqual Band of Diegueno Mission Indians of California
- Santa Rosa Band of Cahuilla Indians
- Santa Rosa Indian Community of the Santa Rosa Rancheria
- Santa Ynez Band of Chumash Mission Indians of the Santa Ynez Reservation
- Santee Sioux Nation
- Sauk-Suiattle Indian Tribe
- Sault Ste. Marie Tribe of Chippewa Indians
- Scotts Valley Band of Pomo Indians of California

- Seldovia Village Tribe
- Seminole Tribe of Florida
- Seneca Nation of Indians
- Seneca-Cayuga Tribe of Oklahoma
- Shageluk Native Village
- Shakopee Mdewakanton Sioux Community of Minnesota
- Shawnee Tribe
- Sherwood Valley Rancheria of Pomo Indians of California
- Shingle Springs Band of Miwok Indians
- Shinnecock Indian Nation
- Shoalwater Bay Indian Tribe of the Shoalwater Bay Indian Reservation
- Shoshone Tribe of the Wind River Reservation
- Shoshone-Bannock Tribes of the Fort Hall Reservation
- Shoshone-Paiute Tribes of the Duck Valley Reservation
- Sisseton-Wahpeton Oyate of the Lake Traverse Reservation
- Sitka Tribe of Alaska
- Skagway Village
- Skokomish Indian Tribe
- Skull Valley Band of Goshute Indians of Utah
- Smith River Rancheria
- Snoqualmie Indian Tribe
- Soboba Band of Luiseno Indians
- Sokaogon Chippewa Community
- South Fork Band (Te-Moak Tribe of Western Shoshone Indians of Nevada)
- South Naknek Village
- Southern Ute Indian Tribe of the Southern Ute Reservation
- Spirit Lake Tribe
- Spokane Tribe of the Spokane Reservation
- Squaxin Island Tribe of the Squaxin Island Reservation
- St. Croix Chippewa Indians of Wisconsin
- Standing Rock Sioux Tribe of North & South Dakota
- Stebbins Community Association
- Stewart Community (Washoe Tribe of Nevada & California)
- Stillaguamish Tribe of Indians of Washington
- Stockbridge Munsee Community
- Summit Lake Paiute Tribe of Nevada
- Sun'aq Tribe of Kodiak
- Suquamish Indian Tribe of the Port Madison Reservation
- Susanville Indian Rancheria

- Swinomish Indians of the Swinomish Reservation
- Sycuan Band of the Kumeyaay Nation
- Table Mountain Rancheria of California
- Takotna Village
- Tangirnaq Native Village
- Tejon Indian Tribe
- Telida Village
- Te-Moak Tribe of Western Shoshone Indians of NV
- The Chickasaw Nation
- The Choctaw Nation of Oklahoma
- The Modoc Tribe of Oklahoma
- The Muscogee (Creek) Nation
- The Osage Nation
- The Quapaw Tribe of Indians
- The Seminole Nation of Oklahoma
- Thlopthlocco Tribal Town
- Three Affiliated Tribes of the Fort Berthold Reservation
- Tohono O'odham Nation of Arizona
- Tonawanda Band of Seneca
- Tonkawa Tribe of Indians of Oklahoma
- Tonto Apache Tribe of Arizona
- Torres Martinez Desert Cahuilla Indians
- Traditional Village of Togiak
- Tulalip Tribes of Washington
- Tule River Indian Tribe of the Tule River Reservation
- Tuluksak Native Community
- Tunica-Biloxi Indian Tribe
- Tuolumne Band of Me-Wuk Indians of the Tuolumne Rancheria of California
- Turtle Mountain Band of Chippewa Indians of North Dakota
- Tuscarora Nation
- Twenty-Nine Palms Band of Mission Indians of California
- Twin Hills Village
- Ugashik Village
- Umkumiut Native Village
- United Auburn Indian Community of the Auburn Rancheria of California
- United Keetoowah Band of Cherokee Indians in Oklahoma
- Upper Sioux Community
- Upper Skagit Indian Tribe
- Ute Indian Tribe of the Uintah & Ouray Reservation

- Ute Mountain Ute Tribe of the Ute Mountain Reservation
- Utu Utu Gwaitu Paiute Tribe of the Benton Paiute Reservation
- Village of Alakanuk
- Village of Anaktuvuk Pass
- Village of Aniak
- Village of Atmautluak
- Village of Bill Moore's Slough
- Village of Chefornak
- Village of Clarks Point
- Village of Crooked Creek
- Village of Dot Lake
- Village of Iliamna
- Village of Kalskag
- Village of Kaltag
- Village of Kotlik
- Village of Lower Kalskag
- Village of Ohogamiut
- Village of Red Devil
- Village of Salamatoff
- Village of Sleetmute
- Village of Solomon
- Village of Stony River
- Village of Venetie
- Village of Wainwright
- Walker River Paiute Tribe of the Walker River Reservation
- Wampanoag Tribe of Gay Head (Aquinnah)
- Washoe Tribe of Nevada & California
- Wells Band
- White Mountain Apache Tribe of the Fort Apache Reservation
- Wichita and Affiliated Tribes
- Wilton Rancheria
- Winnebago Tribe of Nebraska
- Winnemucca Indian Colony of Nevada
- Wiyot Tribe
- Woodfords Community
- Wrangell Cooperative Association
- Wyandotte Nation
- Yakutat Tlingit Tribe
- Yankton Sioux Tribe of South Dakota

- Yavapai-Apache Nation of the Camp Verde Indian Reservation
- Yavapai-Prescott Indian Tribe
- Yerington Paiute Tribe
- Yocha Dehe Wintun Nation
- Yomba Shoshone Tribe of the Yomba Reservation
- Ysleta Del Sur Pueblo
- Yupiit of Andreafski
- Yurok Tribe of the Yurok Reservation
- Zuni Tribe of the Zuni Reservation

10.5 Stakeholders

- AAA Mid-Atlantic, Public and Government Relations
- AirFlow Truck Company
- Alaska Public Interest Research Group
- Alliance of Automobile Manufacturers, Environmental Affairs
- Alliance to Save Energy
- Allison Transmission
- Aluminum Association
- America's Natural Gas Alliance
- American Association of Blacks in Energy
- American Automotive Policy Council
- American Chemistry Council, Plastics
- American Council for an Energy-Efficient Economy
- American Council on Renewable Energy, Biomass Coordinating Council
- American Fuel & Petrochemical Manufacturers, Regulatory Affairs
- American Gas Association
- American Indian Science and Engineering Society
- American International Automobile Dealers Association
- American Iron and Steel Institute
- American Jewish Committee
- American Lung Association
- American Natural Gas Alliance,
- American Powersports Mfg. Co. Inc.
- American Road & Transportation Builders Association (ARTBA)
- American Suzuki Motor Corporation
- American Trucking Associations
- Appalachian Mountain Club
- Arizona Public Interest Research Group
- Association of International Automobile Manufacturers, Inc.

- Association of Metropolitan Planning Organizations
- Auto Research Center
- BAE Systems Platform Solutions
- BlueGreen Alliance
- BMW of North America, LLC
- Border Valley Trading LTD
- Boyden Gray & Associates PLLC
- Bridgestone Americas Tire Operations Product Development Group, Techincal Standards and Regulations
- California Air Pollution Control Officers Association
- CALPIRG (Public Interest Research Group)
- CALSTART
- CATERPILLAR
- Center for Auto Safety
- Center for Biological Diversity
- Center for Biological Diversity, Climate Law Institute
- Central States Air Resources Agencies
- Ceres and the Investor Network on Climate Risk (INCR)
- Chrysler Group LLC
- Citizens' Utility Board of Oregon
- Clean Air Task Force
- Clean Fuel Development Coalition
- Commission for Environmental Cooperation
- Competitive Enterprise Institute
- Con-way Inc
- Conservation Law Foundation
- Consumer Action
- Consumer Assistance Council of Cape Cod
- Consumer Federation of America
- Consumer Federation of the Southeast
- Consumers for Auto Reliability and Safety
- Consumers Union
- Coulomb Technologies, Inc.
- Counteract Balancing Beads
- Criterion Economics, L.L.C.
- Crowell Moring
- Cummins, Inc.
- DAF Trucks
- Daimler AG

- Daimler Trucks North America
- Daimler Vans USA LLC
- Dale Kardos & Associates, Inc.
- Dallas Clean Energy LLC
- Dana Holding Corporation
- Defenders of Wildlife
- Democratic Processes Center
- Detriot Diesel Corporation
- Eaton Corp.
- Ecology Center
- Edison Electric Institute
- Electric Power Research Institute, Electric Transportation & Energy Storage
- Empire State Consumer Association
- Engine Manufacturers Association and Truck Manufacturers Association
- Environment America
- Environment Illinois
- Environmental Defense Fund
- ETEC
- Evangelical Environmental Network, Climate Campaign
- Evangelical Lutheran Church in America
- FedEx Corporation
- Florida Consumer Action Network
- Florida Power & Light Co.
- Ford Motor Company
- Friends Committee on National Legislation
- General Motors
- Gibson, Dunn & Crutcher LLP
- Greater Washington Interfaith Power and Light c/o Interfaith Conference of Metropolitan Washington
- Green Truck Association (GTA)
- Growth Energy
- HayDay Farms, Inc
- HINO
- Honda North America, Inc.
- Hyundai Kia America Technical Center Inc. (HATCI)
- ICM
- Illinois Trucking Association
- Illnois Public Interest Research Group
- Insurance Institute for Highway Safety, VRC Operations

- International Council on Clean Transportation
- Jaguar Land Rover North America LLC
- Jewish Community Relations Council
- Justice and Witness Ministries
- Kenworth Truck Company
- Kirkland & Ellis LLP
- Mack and Volvo Trucks
- Manufacturers of Emission Controls Asociation
- Maryknoll Office of Global Concerns
- Maryland Consumer Rights Coalition
- Maryland Public Interest Research Group
- Massachusetts Consumers Council
- Massachussetts Public Interest Research Group, Transportation
- Mazda North American Operations
- Mercatus Center, George Mason University
- Metro 4, Inc. – Southeastern States Air Resource Managers, Inc.
- Michelin North America, Inc.
- Michigan Tech University, ME-EM Department
- Mid-Atlantic Regional Air Management Association, Inc.
- Mitsubishi Motors North America, Inc.
- Motor & Equipment Manufacturers Association
- National Alliance of Forest Owners
- National Association of Attorneys General
- National Association of Clean Air Agencies
- National Association of Clean Air Agencies (NACAA), NACAA Mobile Sources and Fuels Committee (Massachussetts)
- National Association of Counties
- National Association of Regional Councils
- National Association of Regulatory Utility Commissioners
- National Association of State Energy Officials
- National Automobile Dealers Association
- National Caucus of Environmental Legislators
- National Conference of State Legislatures
- National Council of Churches USA
- National Governors Association
- National Groundwater Association
- National League of Cities
- National Propane Gas Association, Regulatory Affairs
- National Ready Mixed Concrete Association (NRMCA)

- National Truck Equipment Association
- National Wildlife Federation, National Advocacy Center
- Natural Gas Vehicles (NGV) America
- Natural Resources Canada
- Natural Resources Defense Council
- Natural Resources Defense Council, Climate Center
- NAVISTAR Truck Group
- New Jersey Citizen Action
- New Mexico Public Interest Research Group
- Nissan North America, Inc.
- Northeast States for Coordinated Air Use Management
- Nose Cone Manufacturing Company
- NTEA – The Association for the Work Truck Industry
- NY Public Interest Research Group
- Odyne Systems
- Oshkosh Corporation
- Owner-Operator Independent Drivers Association
- Ozone Transport Commission
- PACCAR Inc.
- Peterbilt Motors Company
- Pew Environment Group, Climate and Energy Programs
- Pierobon & Partners
- Podesta GROUP
- Pollution Probe
- Porsche Cars North America, Inc.
- Presbyterian Church (USA)
- Public Citizen
- Recreation Vehicle Industry Association
- Renewable Fuels Association
- Republicans for Environmental Protection
- Road Safe America
- Rocky Mountain Institute
- Rubber Manufacturers Association
- Ryder System, Inc
- Saab Cars North America, Inc.
- Safe Climate Campaign
- Santa Clara Pueblo
- SaviCorp, Inc.
- School Bus Manufacturers Technical Council

- Securing America's Future Energy
- Sentech, Inc.
- Sierra Club
- Socially Responsible Investing, General Board of Pension and Health Benefits of The United Methodist Church
- Society of Plastics, Inc., Industry Affairs – Environment & Health
- Subaru of America
- SUN DAY Campaign
- Teamsters Joint Council 25
- Tesla Motors, Inc.
- Tetlin Village Council
- THE ACCORD GROUP
- The Consumer Alliance
- The Council of State Governments
- The Environmental Council of the States
- The Episcopal Church
- The Hertz Corporation
- The Lee Auto Malls
- The National RV Dealers Association (RVDA)
- The Pew Charitable Trusts, Pew Environment Group
- The Truman National Security Project
- The United Methodist Church General, Board of Church and Society
- Thor Motor Coach
- TIAX LLC
- ToChi Technologies Inc
- Toyota Motor North America, Inc.
- Trillium Asset Management Corporation
- Truck Manufacturer's Association
- Truck Trailer Manufacturers Association
- Trucking and Renting and Leasing Association
- Tufts University, The Fletcher School of Law and Diplomacy
- U.S. Chamber of Commerce
- U.S. Conference of Mayors
- Union for Reform Judaism
- Union of Concerned Scientists
- Union of Concerned Scientists, Clean Vehicles Program
- Union of Concerned Scientists, Washington Office, Clean Vehicles Program
- United Auto Workers
- United Automobile, Aerospace and Agricultural Workers of America (UAW)

- United Church of Christ
- United Steelworkers
- University of Colorado School of Law
- University of Michigan Center for Sustainable Systems
- University of Michigan Transportation Research Institute
- US Public Interest Research Group
- Utility Consumers Action Network
- Vermont Public Interest Research Group
- Victims Committee for Recall of Defective Vehicles
- Virginia Citizens Consumer Council
- Volkswagen Group of America, Inc.
- Volvo Group North America
- Volvo Trucks North America
- Wabash National Corporation
- Waste Management
- West Virginia University
- Western Governors' Association
- Western Regional Air Partnership
- Western States Air Resources Council
- Wisconsin Consumers League
- World Auto Steel
- World Resources Institute, Greenhouse Gas Protocol Team

CHAPTER 11 REFERENCES

21 CTP (21st Century Truck Partnership). 2013. Roadmap and Technical White Papers.

ACIA (Arctic Climate Impact Assessment). 2004. *Impacts of a Warming Arctic*. ACIA Overview Report. Cambridge University Press.

Adar, S. and J. Kaufman. 2007. Cardiovascular Disease and Air Pollutants: Evaluating and Improving Epidemiological Data Implicating Traffic Exposure. *Inhalation Toxicology* 19(S1):135–149.

Adar, S.D., R. Klein, E.K. Klein, A.A. Szpiro, M.F. Cotch, T.Y. Wong, M.S. O'Neill, S. Shrager, R.G. Barr, D.S. Siscovick, M.L. Daviglus, P.D. Sampson, and J.D. Kaufman. 2010. Air Pollution and the Microvasculatory: A Cross-Sectional Assessment of In Vivo Retinal Images in the Population-Based Multi-Ethnic Study of Atherosclerosis. PLoS Med 7(11):E1000372. doi:10.1371/journal.pmed.1000372.

Aero Tech. 2014. Aero Tech Fleet Skirts. *Available at*: http://aerotechfleetproducts.com/trailer-skirts/. (Accessed: April 20, 2015).

AFDC (Alternative Fuels Data Center). 2014a. Biodiesel Vehicle Emissions. Alternative Fuels Data Center, U.S. Department of Energy. *Available at*: http://www.afdc.energy.gov/vehicles/diesels_emissions.html. (Accessed: July 2014).

AFDC. 2014b. Ethanol Vehicle Emissions. Alternative Fuels Data Center, U.S. Department of Energy. *Available at*: http://www.afdc.energy.gov/vehicles/flexible_fuel_emissions.html. (Accessed: July 8, 2014).

AFDC. 2014c. Fuel Properties. *Available at*: http://www.afdc.energy.gov/afdc/fuels/properties.html. (Accessed: July 8, 2014).

Agnolucci, P. 2007. Prospects of Fuel Cell Auxiliary Power Units in the Civil Markets. *International Journal of Hydrogen Energy* 32:4306–4318.

Ainsworth, E. A., and J. M. McGrath. 2010. Direct Effects of Rising Atmospheric Carbon Dioxide and Ozone on Crop Yields. Pgs. 190–130 in Climate Change and Food Security [D. Lobell and M. Burke (Eds.)]. Springer.

Aksoy, M. 1989. Hematotoxicity and Carcinogenicity of Benzene. Environmental Health Perspectives 82:193–197. *Available at*: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1568112/. (Accessed: June 1, 2014).

Aldridge, G., D.W. Inouye, J.R.K. Forrest, W.A. Barr, and A.J. Miller-Rushing. 2011. Emergence of a Mid-season Period of Low Floral Resources in a Montane Meadow Ecosystem Associated with Climate Change. *Journal of Ecology* 99(4):905–913.

Alexeef, S.E., B.A. Coull, A. Gryparis, H. Suh, D. Sparrow, P.S. Vokonas, and J. Schwartz. 2011. Medium-term Exposure to Traffic-related Air pollution and Markers of Inflammation and Endothelial Function. *Environmental Health Perspectives* 119:481–486. doi:10.1289/ehp.1002560.

Alonso, E., T. M. Lee, C. Bjelkengren, R. Roth, and R. E. Kirchain. 2012. Evaluating the Potential for Secondary Mass Savings in Vehicle Lightweighting. *Environmental Science & Technology* 46(5):2893–2901.

Altizer, S., R.S. Ostfeld, P.T. Johnson, S. Kutz, and C.D. Harvell. 2013. Climate Change and Infectious Diseases: From Evidence to a Predictive Framework. *Science* 341(6145):514–519.

Alvarez, R.A., S.W. Pacala, J.J. Winebrake, W.L. Chameides, and S.P. Hamburg. 2012. Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure. P*roceedings of the National Academy of Sciences of the United States* 109(17):6435–6440.

Anderson, C.M., M. Mayes, and R. LaBelle. 2012. Update of Occurrence Rates for Offshore Oil Spills. Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement. *Available at*: http://www.boem.gov/uploadedFiles/BOEM/Environmental_Stewardship/Environmental_Assessment/Oil_Spill_Modeling/AndersonMayesLabelle2012.pdf. (Accessed: June 5, 2014).

Andreae, M.O. and A. Gelencsér. 2006. Black Carbon or Brown Carbon? The Nature of Light-absorbing Carbonaceous Aerosols. Atmospheric Chemistry and Physics 6:3131–3148. *Available at*: http://www.atmos-chem-phys.net/6/3131/2006/acp-6-3131-2006.html. (Accessed: July 31, 2014).

ANL (Argonne National Laboratory). 2013a. AFLEET Tool. Argonne National Laboratory. *Available at*: https://greet.es.anl.gov/afleet. (Accessed: July 8, 2014).

ANL. 2013b. GREET Model. Argonne National Laboratory. *Available at*: https://greet.es.anl.gov/. (Accessed: July 2014).

Appelman, L. M., R.A. Woutersen, and V.J. Feron. 1982. Inhalation Toxicity of Acetaldehyde in Rats. I. Acute and Subacute Studies. *Toxicology* 23(4):293–307.

Appelman, L.M., R.A. Woutersen, V. J. Feron, R.N. Hooftman, and W.R. Notten. 1986. Effect of Variable Versus Fixed Exposure Levels on the Toxicity of Acetaldehyde in Rats. Journal of Applied Toxicology 6(5):331–336. doi: 10.1002/jat.2550060506.

Arnell, N.W. and B. Lloyd-Hughes. 2014. The Global-scale Impacts of Climate Change on Water resources and Flooding under New Climate and Socio-economic Scenarios. *Climatic Change* 122(1–2):127–140.

ATDynamics. 2014a. Aerodynamics 101. *Available at*: http://www.atdynamics.com/aero.htm. (Accessed: July 8, 2014).

ATDynamics. 2014b. Simple Decision. Trailertails are Standard Equipment for the Most Profitable Fleets. *Available at*: http://trailertails.com/. (Accessed: April 20, 2015).

ATDynamics. 2014c. ATDynamics-Transtex Skirts. *Available at*: http://www.atdynamics.com/skirts.htm. (Accessed: July 8, 2014).

ATS (Aerodynamic Trailer Systems). 2014. Smart Tail. *Available at*: http://www.ats-green.com/smarttail.htm. (Accessed: July 8, 2014).

ATSDR (Agency for Toxic Substances and Disease Registry). 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs). U.S Department of Health and Human Services: Atlanta, Georgia.

Available at: http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=122&tid=25. (Accessed: June 28, 2014).

ATSDR (Agency for Toxic Substances and Disease Registry). 1999. Toxicological Profile for Formaldehyde. U.S Department of Health and Human Services: Atlanta, Georgia. Last Revised: March 3, 2011. *Available at*: http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=220&tid=39. (Accessed: June 1, 2014).

ATSDR. 2010. Addendum to the Toxicology Profile for Formaldehyde. U.S. Department of Health and Human Services, Public Health Service. Atlanta, GA, Agency for Toxic Substances and Disease Registry, Division of Toxicology and Environmental Medicine.

Bachman, L.J., A. Erb, and C.L. Bynum. 2005. Effect of Single Wide Tires and Trailer Aerodynamics on Fuel Economy and NOx Emissions of Class 8 Line-Haul Tractor-Trailers. Paper SAE 05CV-45. SAE International.

Balbus, J.M., A.B.A. Boxall, R.A. Fenske, T.E. McKone, and L. Zeise. 2013. Implications of Global Climate Change for the Assessment and Management of Human Health Risks of Chemicals in the Natural Environment. *Environmental Toxicology and Chemistry* 32(1):62–78.

Bandivadekar, A., K. Bodek, L. Cheah, C. Evans, T. Groode, J. Heywood, E. Kasseris, K. Kromer, and M. Weiss. 2008. On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions. Laboratory for Energy and the Environment. Report No. LFEE 2008-05 RP. Cambridge, MA: Massachusetts Institute of Technology. *Available at*: http://web.mit.edu/sloan-auto-lab/research/beforeh2/otr2035/. (Accessed: February 16, 2015).

Banu, S., W. Hu, Y. Guo, C. Hurst, and S. Tong. 2014. Projecting the Impact of Climate Change on Dengue Transmission in Dhaka, Bangladesh. *Environment International* 63:137–142.

Barange, M., G. Merino, J.L. Blanchard, J. Scholtens, J. Harle, E.H. Allison, J.I. Allen, J. Holt, and S. Jennings. 2014. Impacts of Climate Change on Marine Ecosystem Production in Societies Dependent on Fisheries. *Nature Climate Change* 4:211–216.

Baratto, F. and U.M. Diwekar. 2005. Life Cycle Assessment of Fuel Cell-based APUs. *Journal of Power Sources* 139:188–196.

Barber, J.R., K.R. Crooks, and K.M. Fristrup. 2010. The Costs of Chronic Noise Exposure for Terrestrial Organisms. *Trends in Ecology & Evolution* 25(3):180–189.

Barbir, F. 2006. PEM Fuel Cells. Fuel Cell Technology: Reaching Towards Commercialization. *Springer London*: 27–51.

Bardgett, R. D., P. Manning, E. Morriën, and F.T. De Vries. 2013. Hierarchical Responses of Plant–soil Interactions to Climate Change: Consequences for the Global Carbon Cycle. *Journal of Ecology* 101(2):334–343.

Baron, J. S., E.K. Hall, B.T. Nolan, J.C. Finlay, E.S. Bernhardt, J.A. Harrison, F. Chan, and E.W. Boyer. 2013. The Interactive Effects of Excess Reactive Nitrogen and Climate Change on Aquatic Ecosystems and Water Resources of the United States **citing** EPA (U.S. Environmental Protection Agency). 2011. Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences and Management Options. A Report of the US EPA Science Advisory Board. *Biogeochemistry* 114(1–3):71–92.

Bassiouni, M. and D.S. Oki. 2013. Trends and Shifts in Streamflow in Hawaii, 1913–2008. *Hydrological Processes* 27(10):1484–1500.

Bates, B., Z. W. Kundzewicz, S. Wu, and J. Palutikof (eds.). 2008. Climate Change and Water: Technical Paper of the Intergovernmental Panel on Climate Change. Geneva, CH, IPCC Secretariat.

Battye, W., K. Boyer, and T.G. Pace. 2002. Methods for Improving Global Inventories of Black Carbon and Organic Carbon Particulates. 11th International Emission Inventory Conference, Emission Inventories-Partnering for the Future, Atlanta, GA, EPA (Environmental Protection Agency).

Baumers, M., C. Tuck, R. Wildman, L. Ashcroft, and R. Hague. 2011. Energy Inputs to Additive Manufacturing: Does Capacity Utilization Matter? Additive Manufacturing Research Group, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University.

BCDC (San Francisco Bay Conservation and Development Commission). 2009. Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline **citing** Heberger, M., H. Cooley, P. Herrera, P.H. Gleick, and E. Moore. 2009. The Impacts of Sea-level Rise on the California Coast. Prepared by California Climate Change Center, Sacramento, California. California Energy Commission.

BEA (Bureau of Economic Analysis, National Income, and Product Accounts). 2014. (NIPA) Table 1.1.9, Implicit Price Deflators for Gross Domestic Product. *Available at*: http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&903=13. (Accessed: June 9, 2014).

Beane Freeman, L. E., A. Blair, J.H. Lubin, P.A. Stewart, R.B. Hayes, R.N. Hoover, and M. Hauptmann. 2009. Mortality from Lymphohematopoietic Malignancies among Workers in Formaldehyde Industries: The National Cancer Institute Cohort. Journal of the National Cancer Institute 101(10):751–761. doi: 10.1093/jnci/djp096. *Available at*: http://jnci.oxfordjournals.org/content/101/10/751.full.pdf+html. (Accessed: June 1, 2014).

Bertram, M., K. Buxmann, and P. Furrer. 2009. Analysis of Greenhouse Gas Emissions Related to Aluminum Transport Applications. *The International Journal of Life Cycle Assessment* 14(1):62–69.

Bevan, C., J. C. Stadler, G. S. Elliott, S. R. Frame, J. K. Baldwin, H.-W. Leung, E. Morna, and A. S. Panepinto. 1996. Subchronic Toxicity of 4-vinylcyclohexene in Rats and Mice by Inhalation Exposure. Toxicological Sciences 32(1):1–10. doi: 10.1093/toxsci/32.1.1. *Available at*: http://toxsci.oxfordjournals.org/content/32/1/1.full.pdf+html. (Accessed: June 1, 2014).

BIA (Bureau of Indian Affairs). 2014. Alaska Region Overview. U.S. Department of the Interior, Bureau of Indian Affairs. *Available at*: http://www.bia.gov/WhoWeAre/RegionalOffices/Alaska/. (Accessed: June 9, 2014).

Birat, J.P., L. Rocchia, V. Guérin, and M. Tuchman. 2003. Ecodesign of the Automobile, Based on Steel Sustainability. Paper SAE 2003-01-2850. Society of Automotive Engineers (SAE) International.

Birk, T., and K. Rasmussen. 2014. Migration from Atolls as Climate Change Adaptation: Current Practices, Barriers and Options in Solomon Islands. *Natural Resources Forum* 38(1):1–13, Wiley Online Library.

Black, H. 2008. The Mighty Microbe. Some Scientists Fear CO2-spewing Bacteria Will Speed Global Warming. Milwaukee Journal Sentinel.

Blake, E. S., C.W. Landsea, and E.J. Gibney. 2011. The Deadliest, Costliest, and Most Intense United States Tropical Cyclones from 1851 to 2006 (and Other Frequently Requested Hurricane Facts). NOAA Technical Memorandum NWS NHC-6, NOAA/National Weather Service, National Centers for Environmental Prediction, National Hurricane Center.

Bloetscher, F., B. Heimlich, and D.E. Meeroff. 2011. Development of An Adaptation Toolbox to Protect Southeast Florida Water Supplies from Climate Change. *Environmental Reviews* 19:397–417.

Bobb, J. F., R.D. Peng, M.L. Bell, and F. Dominici. 2014. Heat-related Mortality and Adaptation to Heat in the United States. Environmental Health Perspectives 122(8):811–816.

Boehmer, T. K., S.L. Foster, J.R. Henry, E.L. Woghiren-Akinnifesi, and F. Y. Yip. 2013. Residential Proximity to Major Highways – United States, 2010. *Morbidity and Mortality Weekly Report* 62(3):46–50.

Boland, C., R. DeKleine, A. Moorthy, G. Keoleian, H.C. Kim, E. Lee, and T.J. Wallington. 2014. A Life Cycle Assessment of Natural Fiber Reinforced Composites in Automotive Applications. SAE Technical Paper 2014-01-1959. *Available at*: http://papers.sae.org/2014-01-1959/. (Accessed: July 8, 2014).

Bond, T. C., D.G. Streets, K.F. Yarber, S.M. Nelson, J.-H. Woo, and Z. Klimont. 2004. A Technology-based Global Inventory of Black and Organic Carbon Emissions from Combustion. *Journal of Geophysical Research: Atmospheres* (1984–2012) 109(D14):203.

Bond, T. C., S. J. Doherty, D. W. Fahey, P. M. Forster, T. Berntsen, B. J. DeAngelo, M. G. Flanner, S. Ghan, B. Kärcher, D. Koch, S. Kinne, Y. Kondo, P. K. Quinn, M. C. Sarofim, M. G. Schultz, M. Schulz, C. Venkataraman, H. Zhang, S. Zhang, N. Bellouin, S. K. Guttikunda, P. K. Hopke, M. Z. Jacobson, J. W. Kaiser, Z. Klimont, U. Lohmann, J. P. Schwarz, D. Shindell, T. Storelvmo, S. G. Warren, and C. S. Zender. 2013. Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment. *Journal of Geophysical Research: Atmospheres* 118(11):5380–5552.

Boothe, V.L. and Shendell, D.G. 2008. Potential Health Effects Associated with Residential Proximity to Freeways and Primary Roads: Review of Scientific Literature, 1999–2006. *Journal of Environmental Health* 70:33–41.

Boothe, VL., T.K. Boehmer, A.M. Wendel, and F.Y. Yip. 2014. Residential Traffic Exposure and Childhood Leukemia: A Systematic Review and Meta-analysis. *Am J Prev Med* 46:413-422.

Borasin, S., et al. 2002. Oil: A Life Cycle Analysis of its Health and Environmental Impacts. *Available at*: http://www.chgeharvard.org/resource/oil-life-cycle-analysis-its-health-and-environmental-impacts. (Accessed: May 23, 2014).

Boumans, R. J. M., D.L. Phillips, W. Victery, and T.D. Fontainel. 2014. Developing a Model for Effects of Climate Change on Human Health and Health-environment Interactions: Heat Stress in Austin, Texas. *Urban Climate* 8:78–99.

Bowles, A. E. 1995. Responses of Wildlife to Noise In: Wildlife and Recreationists: Coexistence through Management and Research. Washington, DC [R.L. Knight and K.J. Gutzwiller (Eds.)], Island Press, Washington.

Brander, K. 2010. Impacts of Climate Change on Fisheries. *Journal of Marine Systems* 79(3):389–402.

Brandt, A. R., G. A. Heath, E. A. Kort, F. O'Sullivan, G. Pétron, S. M. Jordaan, P. Tans, J. Wilcox, A. M. Gopstein, D. Arent, S. Wofsy, N. J. Brown, R. Bradley, G. D. Stucky, D. Eardley, and R. Harriss. 2014. Methane Leaks from North American Natural Gas Systems. *Science* 343(6172):733–735.

Brekke, L. D., J. E. Kiang, J. R. Olsen, R. S. Pulwarty, D. A. Raff, D. P. Turnipseed, R. S. Webb, and K. D. White. 2009. Climate Change and Water Resources Management: A Federal Perspective. U.S. Geological Survey Circular 1331.

Brodrick, C., Lipman, T. E., Farshchi, M., Lutsey, N. P., Dwyer, H. A., Sperling, D., Gouse III, S. W., Harris, D. B., and F. G. King. 2002. Evaluation of Fuel Cell Auxiliary Power Units for Heavy-Duty Diesel Trucks. *Transportation Research Part D* 7:303–315.

Bronen, R., and F. S. Chapin. 2013. Adaptive Governance and Institutional Strategies for Climate-induced Community Relocations in Alaska. *Proceedings of the National Academy of Sciences* 110:23.

Brown, C. L., S. E. Reed, M. S. Dietz, and K. M. Fristrup. 2013. Detection and Classification of Motor Vehicle Noise in a Forested Landscape. *Environmental Management* 52(5):1262–1270.

Brown, S., S. Hanson, and R. J. Nicholls. 2014. Implications of Sea-level Rise and Extreme Events around Europe: A Review of Coastal Energy Infrastructure. *Climatic Change* 122(1-2):81–95.

Browning-Aiken, A., B. Morehouse, A. Davis, M. Wilder, R. Varady, D. Goodrich, R. Carter, D. Moreno, and E. D. McGovern. 2007. Climate, Water Management, and Policy in the San Pedro Basin: Results of a Survey of Mexican Stakeholders near the US–Mexico Border. *Climatic Change* 85(3-4):323–341.

Bulka, C., L.J. Nastoupil, W. McClellan, A. Ambinder, A. Phillips, K. Ward, A. R. Bayakly, J. M. Switchenko, L. Waller, and C. R. Flowers. 2013. Residence Proximity to Benzene Release Sites is Associated with Increased Incidence of Non-Hodgkin Lymphoma. *Cancer* 119(18):3309–3317.

Burge, C. A., C. Mark Eakin, C. S. Friedman, B. Froelich, P. K. Hershberger, E. E. Hofmann, L. E. Petes, K. C. Prager, E. Weil, B. l. Willis, S. E. Ford, and C. D. Harvell. 2014. Climate Change Influences on Marine Infectious Diseases: Implications for Management and Society. *Annual Review of Marine Science* 6:249–277.

Burkett, V. R., D. A. Wilcox, R. Stottlemyer, W. Barrow, D. Fagre, J. Baron, J. Price, J. L. Nielsen, C. D. Allen, D. L. Peterson, G. Ruggerone, and T. Doyle. 2005. Nonlinear Dynamics in Ecosystem Response to Climatic Change: Case Studies and Policy Implications. *Ecological Complexity* 2(4):357–394.

Burton, I. 2008. Climate Change and the Adaptation Deficit. London, UK: Routledge.

Butscher, C., and P. Huggenberger. 2009. Modeling the Temporal Variability of Karst Groundwater Vulnerability, with Implications for Climate Change. *Environmental Science & Technology* 43(6):1665–1669.

C2ES (Center for Climate and Energy Solutions). 2014a. California Cap and Trade. *Available at*: http://www.c2es.org/us-states-regions/key-legislation/california-cap-trade. (Accessed: June 23, 2014).

C2ES. 2014b. Freight Transportation. *Available at*: http://www.c2es.org/technology/factsheet/FreightTransportation. (Accessed: June 24, 2014).

C2ES. 2014c. Medium- and Heavy-Duty Vehicles. *Available at*: http://www.c2es.org/technology/Medium-and-Heavy-DutyVehicles. (Accessed: June 3, 2014).

C2ES. 2014d. Regional Greenhouse Gas Initiative. *Available at*: http://www.c2es.org/us-states-regions/regional-climate-initiatives/rggi. (Accessed: June 2, 2014).

Cáceres, C.H. 2009. Transient Environmental Effects of Light Alloy Substitutions in Transport Vehicles. Materials & Design 30(8):2813–2822. doi: 10.1016/j.matdes.2009.01.027.

Cahill, A.E., M.E. Aiello-Lammens, M. Caitlin Fisher-Reid, X. Hua, C.J. Karanewsky, H.Y. Ryu, G.C. Sbeglia, F. Spagnolo, J.B. Waldron, O. Warsi, and J.J. Wiens. 2013. How Does Climate Change Cause Extinction? Proceedings of the Royal Society B 280:20121890.

Caldeira, K., and M. E. Wickett. 2005. Ocean Model Predictions of Chemistry Changes from Carbon Dioxide Emissions to the Atmosphere and Ocean. *Journal of Geophysical Research: Oceans* (1978–2012) 110(C9):S4.

California Department of Transportation. 2007. The Effects of Highway Noise on Birds. Prepared by Robert J. Dooling and Arthur N. Popper of the University of Maryland: 74 pgs.

Caminade, C., S. Kovats, J. Rocklov, A. M. Tompkins, A. P. Morse, F. J. Colón-González, H. Stenlund, P. Martens, and S. J. Lloyd. 2014. Impact of Climate Change on Global Malaria Distribution. *Proceedings of the National Academy of Sciences* 111(9):3286–3291.

Canadell, J.G., C. Le Quére, M.R. Raupach, C.B. Field, E.T. Buitenhuis, P. Ciais, T.J. Conway, N.P. Gillett. 2007. Contributions to Accelerating Atmospheric CO2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks. *Proceedings of the National Academy of Sciences* 104(47):18866–18870.

Canadian National Energy Board. 2014. Estimated Canadian Crude Oil Exports by Type and Destination. *Available at*: http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/sttstc/crdlndptrlmprdct/stmtdcndncrdlxprttpdstn-eng.html#s2013. (Accessed: July 8, 2014).

Cao, L., G. Bala, K. Cladeira, R. Nemani, and G. Ban-Weiss. 2010. Importance of Carbon Dioxide Physiological Forcing to Future Climate Change. *Proceedings of the National Academy of Sciences* 107(21):9513–9518.

Cape, J. N., I. D. Leith, J. Binnie, J. Content, M. Donkin, M. Skewes, D. N. Price, A. R. Brown, and A. D. Sharpe. 2003. Effects of VOCs on Herbaceous Plants in an Open-top Chamber Experiment. *Environmental Pollution* 124(2):341–353. doi: 10.1016/s0269-7491(02)00464-5.

CARB (California Air Resources Board). 2014. First Update to the Climate Change Scoping Plan: Building on the Framework Pursuant to AB 32, California Air Resources Board.

Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov. 2010. Future Dryness in the Southwest US and the Hydrology of the Early 21st Century Drought. *Proceedings of the National Academy of Sciences* 107(50):21271–21276.

CCSP (U.S. Climate Change Science Program). 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Report for the U.S. Global Change Research Program. Cambridge, UK: Cambridge University Press.

CCSP. 2003. Strategic Plan for the U.S. Climate Change Science Program. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. Washington DC: U.S. Climate Change Science Program Office.

CCSP. 2008a. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems. Prepared by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. EPA., Washington, DC.

CCSP. 2008b. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC.

CCSP. 2008c. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems. Prepared by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.L. Gamble, K.L. Ebi, F.G. Sussman, and T.J. Wilbanks (Eds.)]. U.S. EPA. Washington, DC **citing** Cook, J. T., and D. A. Frank. 2007. Food Security, Poverty, and Human Development in the United States. Annals of the New York Academy of Sciences 1–16.

CCSP. 2009. Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC, National Aeronautics and Space Administration.

CEM (Council of Energy Ministers). 2009. On the Road to a Fuel-Efficient Truck, 2009. *Available at*: http://www.worldcat.org/title/on-the-road-to-a-fuel-efficient-truck-a-guide-for-purchasing-aerodynamics-for-heavy-duty-tractors-and-trailers/oclc/609560736. (Accessed: April 20, 2015).

CEQ (Council on Environmental Quality). 1997. Environmental Justice Guidance under the National Environmental Policy Act. Washington, DC, Council on Environmental Quality: 40 pgs.

CEQ. 2012. Federal Greenhouse Gas Accounting and Reporting Guidance. *Available at*: https://www.whitehouse.gov/sites/default/files/microsites/ceq/revised_federal_greenhouse_gas_accounting_and_reporting_guidance_060412.pdf. (Accessed: June 17, 2015).

Chan, C.-C., R. H. Shie, T. Y. Chang, and D. H. Tsai. 2006. Workers' Exposures and Potential Health Risks to Air Toxics in a Petrochemical Complex Assessed by Improved Methodology. *International Archives of Occupational and Environmental Health* 79(2):135–142.

Cheah, L. 2010. Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S. Massachusetts Institute of Technology: Cambridge, MA. *Available at*: http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/LCheah_PhD_thesis_2010.pdf. (Accessed: July 3, 2014).

Cheah, L., and J. B. Heywood. 2011. Meeting U.S. Passenger Vehicle Fuel Economy Standards in 2016 and Beyond. Energy Policy 39:454–466. *Available at*: https://ideas.repec.org/a/eee/enepol/v39y2011i1p454-466.html. (Accessed: July 8, 2014).

Cheah, L., J. B. Heywood, and R. Kirchain. 2009. Aluminum Stock and Flows in U.S. Passenger Vehicles and Implications for Energy Use. *Journal of Industrial Ecology* 13(5):718–734.

Chen, W.-Q., and T. Graedel. 2012. Anthropogenic Cycles of the Elements: A Critical Review. *Environmental Science & Technology* 46(16):8574–8586.

Chen, W.-Q., and T. Graedel. 2012. Dynamic Analysis of Aluminum Stocks and Flows in the United States: 1900–2009. *Ecological Economics* 81:92–102.

Cheng, J. J., and P. Berry. 2013. Health Co-benefits and Risks of Public Health Adaptation Strategies to Climate Change: A Review of Current Literature. *International Journal of Public Health* 58(2):305–311.

Cheung, W. W. L., R. Watson, and D. Pauly. 2013. Signature of Ocean Warming in Global Fisheries Catch. *Nature* 497(7449):365–368.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W. T. Kwon, R. Laprise, V. M. Rueda, L. Mearns, C. G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. 2007. Regional Climate Projections. Pgs. 847–940 In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds.)]. Cambridge University Press: Cambridge, United Kingdom and New York, New York. 996 pgs. *Available at*: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. (Accessed: August 12, 2014).

Christensen, J. H., K. Krishna Kumar, E. Aldrian, S.-I. An, I. F. A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J. K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D. B. Stephenson, S.-P. Xie and T. Zhou. 2013. Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Clark, P. U., A. J. Weaver, E. Brook, E. R. Cook, T. L. Delworth, and K. Steffen. 2008. Abrupt Climate Change. Prepared by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Geological Survey. Reston, Virginia.

Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels. 2007. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations: Sub-Report 2.1A of Sunthesis and Assessment Product 2.1 by the Climate Change Science Program and the Subcommittee on Global Change Research: Office of Biological and Environmental Research. US Department of Energy Publications.

Clow, D. 2010. Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. *Journal of Climate* 23(9):2293–2230.

CNA Corporation. 2007. National Security and the Threats of Climate Change. Alexandria, VA. *Available at*: https://www.cna.org/reports/climate. (Accessed: June 17, 2015).

CNA Corporation. 2014. National Security and the Accelerating Risks of Climate Change. Alexandria, VA. *Available at*: https://www.cna.org/reports/accelerating-risks. (Accessed: June 17, 2015).

Coggon, D., E. C. Harris, J. Poole, and K. T. Palmer. 2003. Extended Follow-up of a Cohort of British Chemical Workers Exposed to Formaldehyde. *Journal of the National Cancer Institute* 95(21):1608–1615. doi: 10.1093/jnci/djg046. *Available at*: http://jnci.oxfordjournals.org/content/95/21/1608.full.pdf+html. (Accessed: June 1, 2014).

Colett, J. 2013. Impacts of Geographic Variation on Aluminum Lightweighted Plug-in Hybrid Electric Vehicle Greenhouse Gas Emissions. University of Michigan: Ann Arbor, MI. *Available at*: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/101902/Joe%20Colett%20Thesis%20December%202013.pdf?sequence=1. (Accessed: July 8, 2014).

Colón-González, F. J., C. Fezzi, I. R. Lake, and P. R. Hunter. 2013. The Effects of Weather and Climate Change on Dengue. *PLoS Neglected Tropical Diseases* 7(11):e2503.

Comte, L., L. Buisson, M. Daufresne, and G. Grenouillet. 2013a. Climate-induced Changes in the Distribution of Freshwater Fish: Observed and Predicted Trends. *Freshwater Biology* 58(4):625–639.

Comte, L., L. Buisson, M. Daufresne, and G. Grenouillet. 2013b. Climate-induced Changes in the Distribution of Freshwater Fish: Observed and Predicted Trends **citing** Isaak, D. J., C. H. Luce, B. E. Rieman, D. E. Nagel, E. E. Peterson, D. L. Horan, and G. L. Chandler. 2010. Effects of Climate Change and Wildfire on Stream Temperatures and Salmonid Thermal Habitat in a Mountain River Network. Ecological Applications 20(5):1350–1371. *Freshwater Biology* 58(4):625–639.

Congressional Budget Office (CBO). 2009. The Impact of Ethanol Use on Food Prices and Greenhouse-Gas Emissions. The Congress of the United States. Pub. No. 3155. *Available at*: http://www.cbo.gov/publication/41173. (Accessed: October 8, 2014).

Cook, R., J. S. Touma, A. Beidler, and M. Strum. 2006. Preparing Highway Emissions Inventories for Urban Scale Modeling: A Case Study in Philadelphia. Transportation Research Part D: Transport and Environment 11(6):396–407. doi: 10.1016/j.trd.2006.08.001.

Cubasch, U., D. Wuebbles, D. Chen, M.C. Facchini, D. Frame, N. Mahowald, and J.-G. Winthe. 2013. Introduction. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, Cambridge University Press.

Curtis, K. J., and A. Schneider. 2011. Understanding the Demographic Implications of Climate Change: Estimates of Localized Population Predictions under Future Scenarios of Sea-level Rise. *Population and Environment* 33(1):28–54.

Cutter, L. S., B. J. Boruff, and W. L. Shirley. 2003. Social Vulnerability to Environmental Hazards. *Social Science Quarterly* 84(2).

D'Amato, G., C. E. Baena-Cagnani, L. Cecchi, I. Annesi-Maesano, C. Nunes, I. Ansotegui, M. D'Amato, G. Liccardi, M. Sofia,and W. G. Canonica. 2013. Climate Change, Air Pollution and Extreme Events Leading to Increasing Prevalence of Allergic Respiratory Diseases. *Multidisciplinary Respiratory Medicine* 8(1):12.

Das, S. 2011. Life Cycle Assessment of Carbon Fiber-Reinforced Polymer Composites. *International Journal of Life Cycle Assessment* 16:268–282.

Das, S. 2014. Life Cycle Energy and Environmental Assessment of Aluminum-Intensive Vehicle Design. *SAE International Journal of Material Manufacturing* 7(3):2014.

Davis, S. C., S. W. Diegel, and R. G. Boundy. 2013. Transportation Energy Data Book, 32th Edition. Oak Ridge National Laboratory: Oak Ridge, Tennessee. *Available at*: http://info.ornl.gov/sites/publications/files/Pub44660.pdf. (Accessed: April 20, 2015).

Daw, C., Z. Gao, D. Smith, T. LaClair, J. A. Pihl, and K. D. Edwards. 2013. Simulated Fuel Economy and Emissions Performance during City and Interstate Driving for a Heavy-Duty Hybrid Truck. *SAE International Journal of Commercial Vehicles* 6(1):161–182.

DOD (Department of Defense). 2014. Quadrennial Defense Review 2014. U. S. Department of Defense. Washington, DC.

DOE (U.S. Department of Energy). 2009. Strategies for the Commercialization and Deployment of Greenhouse Gas Intensity-Reducing Technologies and Practices. U.S. Department of Energy. Last Revised: March 2014. *Available at*: http://energy.gov/node/353617. (Accessed: June 6, 2014).

DOE. 2014a. Appliance and Equipment Standards Program. *Available at*: http://energy.gov/eere/buildings/appliance-and-equipment-standards-result-large-energy-economic-and-environmental. (Accessed: June 4, 2014).

DOE. 2014b. Saving Energy and Money with Appliance and Equipment Standards in the United States. *Available at*: http://www1.eere.energy.gov/buildings/pdfs/saving_with_appliance_and_equipment_standards.pdf. (Accessed: June 4, 2014).

DOE. 2014c. SuperTruck Making Leaps in Fuel Efficiency. *Available at*: http://energy.gov/eere/articles/supertruck-making-leaps-fuel-efficiency. (Accessed: July 16, 2014).

DOE: 2014d. Office of Energy Efficiency & Renewable Energy. Federal Greenhouse Gas Inventories and Performance.

DOI (U.S. Department of the Interior). 2005. Water 2025—Preventing Crises and Conflict in the West. Washington DC: U.S. Department of the Interior.

Doney, S.C. 2009. The Consequences of Human-driven Ocean Acidification for Marine Life. *F1000 Biology Reports* 1(36):1–4

Doney, S.C., W.M. Balch, V.J. Fabry, and R.A. Feely. 2009. Ocean Acidification: A Critical Emerging Problem for the Ocean Sciences. *Oceanography* 22:16–25.

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean Acidification: The Other CO2 Problem. *Annual Review of Marine Science* 1:169–192.

DOT (U.S. Department of Transportation). 2013. Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses. Memorandum to Secretarial officers and Modal Administrators from Polly Trottenberg and Robert S. Rivkin. Washington, DC.

Available at: http://www.dot.gov/office-policy/transportation-policy/guidance-treatment-economic-value-statistical-life. (Accessed: April 20, 2015).

DOT. 2014a. Guidance on Accelerated Decision Making in Environmental Reviews. *Available at*: http://www.dot.gov/office-policy/transportation-policy/guidance-accelerated-decision-making-environmental-reviews. (Accessed: May 4th, 2015).

DOT. 2014b. U.S. Department of Transportation Climate Adaptation Plan 2014: Ensuring Transportation Infrastructure and System Resilience. *Available at*: http://www.dot.gov/sites/dot.gov/files/docs/2014-%20DOT-Climate-Adaptation-Plan.pdf. (Accessed: April 20, 2015).

Douglas, E., P. Kirshen, V. Li, C. Watson, and J. Wormser. 2013. Preparing for the Rising Tide. Environmental, Earth, and Ocean Sciences Faculty Publication Series.

Douglass, S. L., B. M. Webb, and R. Kilgore. 2014. Hydraulic Engineering Circular No. 25 (Volume 2) Highways in the Coastal Environment: Assessing Extreme Events. Federal Highway Administration. *Available at*: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi14006/nhi14006.pdf. (Accessed: February 16, 2015).

Dubowsky Adar, S., G. Adamkiewicz, D. R. Gold, J. Schwartz, B. A. Coull, and H. Suh. 2007. Ambient and Microenvironmental Particles and Exhaled Nitric Oxide before and after a Group Bus Trip. *Environmental Health Perspectives* 115:507–512.

Dubreuil, A., L. Bushi, S. Das, A. Tharumarajah, and G. Xianzheng. 2010. A Comparative Life Cycle Assessment of Magnesium Front End Autoparts. Presented at SAE 2010 World Congress and Exhibition. *Available at*: http://papers.sae.org/2012-01-2325/. (Accessed: April 20, 2015).

Dukes, J. S., J. Pontius, D. Orwig, J. R. Garnas, V. L. Rodgers, N. Brazee, B. J. Cooke, K. A. Theoharides, E. E. Strange, R. Harrington, J. Ehrenfeld, J. Gurevitch, M. Lerdau, K. Stinson, and R. Wick. 2009. Responses of Insect Pests, Pathogens, and Invasive Plant Species to Climate Change in the Forests of Northeastern North America: What Can We Predict? NE Forests 2100: A Synthesis of Climate Change Impacts on Forests of the Northeastern US and Eastern Canada. Canadian Journal of Forest Research 39(2):231–248.

Durack, P. J., and S. E. Wijffels. 2010. Fifty-year Trends in Global Ocean Salinities and their Relationship to Broad-scale Warming. *Journal of Climate* 23(16):4342–4362.

Duveneck, M. J., R. M. Scheller, M. A. White, S. D. Handler, and C. Ravenscroft. 2014. Climate Change Effects on Northern Great Lake (USA) Forests: A Case for Preserving Diversity. Ecosphere 5(2):23.

Ebi, K., J. Balbus, P. L. Kinney, E. Lipp, D. Mills, M. S. O'Neill, and M. Wilson. 2008. Effects of Global Change on Human Health. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems. U.S. Climate Change Science Program and the Subcommittee on Global Change Research **citing** Leung, R. L., and W. I. Gustafson Jr. 2005. Potential Regional Climate Change and Implications to U.S. Air Quality. Geophysical Research Letters 32(16):L16711. CCSP (U.S. Climate Change Science Program). Washington, DC

Eckel. S. P., K. Berhane, M. T. Salam, E. B. Rappaport, W. S. Linn, T. M. Bastain, Y. Zhang, F. Lurmann, E. L. Avol, and F. D. Gilliland. 2011. Residential Traffic-related Pollution Exposure and Exhaled Nitric Oxide in the Children's Health Study. Environmental Health Perspectives 119:1472–1477. doi:10.1289/ehp.1103516.

EcoVet Furniture. 2014. Aerosmart Trailer Skirts. *Available at*: http://www.ecovetusa.com/aerosmart-trailer-skirting/. (Accessed: April 20, 2015).

Edge Skirts, 2014. Edge by Transtex—Family of Solutions. *Available at*: http://edgeskirts.com/. (Accessed: July 8, 2014).

EEA (Energy and Environmental Analysis, Inc.). 2006. Technology to Improve the Fuel Economy of Light Trucks to 2015. Report to the Department of Energy and Department of Transportation.

Ehrenberger, S. 2013. Life Cycle Assessment of Magnesium Components in Vehicle Construction. German Aerospace Centre e.V. Institute of Vehicle Concepts.

EIA (Energy Information Administration). 2006. Annual Energy Outlook 2006 with Projections to 2030. U.S. Department of Energy, U.S. Energy Information Administration.

EIA. 2009. Top 100 Oil and Gas Fields of 2009. U.S. Department of Energy, U.S. Energy Information Administration. *Available at*: www.eia.gov/naturalgas/crudeoilreserves/top100/pdf/top100.pdf. (Accessed: April 20, 2015).

EIA. 2010. Annual Energy Outlook 2010 with Projections to 2035. U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy.

EIA. 2011. Annual Energy Outlook 2011. DOE/EIA-0383. U.S. Department of Energy: Washington, DC. *Available at*: http://www.eia.gov/forecasts/archive/aeo11/. (Accessed: August 9, 2014).

EIA. 2013. The U.S. Relies on Foreign Uranium, Enrichment Services to Fuel its Nuclear Power Plants: Uranium Marketing Annual Report. August 28, 2013. *Available at*: http://www.eia.gov/todayinenergy/detail.cfm?id=12731. (Accessed: February 16, 2015).

EIA. 2014a. Annual Energy Outlook 2014 with Projections to 2040. *Available at*: http://www.eia.gov/forecasts/aeo/. (Accessed: February 16, 2015).

EIA. 2014b. International Energy Statistics, Total Primary Energy Consumption. *Available at*: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2. (Accessed: February 16, 2015).

EIA. 2014c. Table 1: World Total Primary Energy Consumption by Region, Reference Case: 2009-2040. *Available at*: http://www.eia.gov/forecasts/archive/aeo14/. (Accessed: February 16, 2015).

Eick, S. 2012. Heavy Duty Diesel Truck and Bus Hybrid Powertrain Study Performing agency: Select Engineering Services (SES). Prepared for U.S. Army. *Available at*: http://www.dtic.mil/dtic/tr/fulltext/u2/a567008.pdf. (Accessed: July 8, 2014).

Encyclopedia Britannica, Inc. 2014. Keystone Species. *Available at*: www.britannica.com/EBchecked/topic/315977/keystone-species. (Accessed: June 2, 2014).

Entrekin, S., M. Evans-White, B. Johnson, and E. Hagenbuch. 2011. Rapid Expansion of Natural Gas Development Poses a Treat to Surface Waters. *Frontiers in Ecology and the Environment 2011* 9(9):503–511.

EPA. 1989. Integrated Rick Information System File of Formaldehyde. (CASRN 50-00-0). *Available at*: http://www.epa.gov/iris/subst/0419.htm. (Accessed: June 30, 2014).

EPA. 1995. Office of Compliance Sector Notebook: Profile of the Petroleum Refining Industry. Washington, DC. 146 pgs.

EPA. 1997. Integrated Risk Information System File of Indenol [1,2,3-cd] pyrene. (CASRN 193-39-5). *Available at*: http://www.epa.gov/ncea/iris/subst/0457.htm. (Accessed: June 29, 2014).

EPA. 1998. Integrated Risk Information System File of Acetaldehyde. (CASRN 75-07-0). *Available at*: http://www.epa.gov/iris/subst/0290.htm. (Accessed: June 4, 2014).

EPA. 1999. Office of Compliance Sector Notebook: Profile of the Oil and Gas Extraction Industry. Washington DC: U.S. Environmental Protection Agency. 165 pgs.

EPA. 2000a. Integrated Risk Information System File of Benzene. (CASRN 71-43-2). U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment: Washington, DC. *Available at*: http://www.epa.gov/iris/subst/0276.htm. (Accessed: June 4, 2014).

EPA. 2000b. Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements: Final Rule: 40 CFR Parts 80, 85, and 86, U.S. Environmental Protection Agency. Last Revised: January 10, 2011. *Available at*: http://www.epa.gov/oms/documents/tier3/420r14005.pdf. (Accessed: June 4, 2014).

EPA. 2001. A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. Draft Technical Report. EPA420-P-02-001. U.S. Environmental Protection Agency, Office of Transportation and Air Quality. *Available at*: http://epa.gov/otaq/models/analysis/biodsl/p02001.pdf. (Accessed: July 2014).

EPA. 2002a. Toxicology Review of Benzene (Noncancer Effects) in Support of Summary Information on the Integrated Risk Information System (IRIS). (CAS No. 71-43-2). Washington DC: U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment: Washington, DC. *Available at*: http://www.epa.gov/iris/toxreviews/0276tr.pdf. (Accessed: June 4, 2014).

EPA. 2002b. Health Assessment of 1,3-Butadiene. EPA-600-P-98-001F. *Available at*: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=54499. (Accessed: June 4, 2014).

EPA. 2002c. Integrated Risk Information System File for 1,3-Butadiene. (CASRN 106-99-0). *Available at*: http://www.epa.gov/iris/subst/0139.htm. (Accessed: June 4, 2014).

EPA. 2002d. Health Assessment Document for Diesel Engine Exhaust. EPA/600/8-90/057F Office of Research and Development, Washington DC. Docket EPA-HQ-OAR-2010-0799. *Available at*: http://www.epa.gov/ttn/atw/dieselfinal.pdf. (Accessed: July 5, 2012).

EPA. 2003a. Toxicological Review of Acrolein in Support of Summary Information on the Integrated Risk Information System (IRIS). EPA/635/R-03/003. Washington DC: U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment: Washington, DC. *Available at*: http://www.epa.gov/ncea/iris/toxreviews/0364tr.pdf. (Accessed: June 4, 2014).

EPA. 2003b. Integrated Risk Information System (IRIS) File of Acrolein. (CASRN 107-02-08). U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment: Washington, DC. *Available at*: http://www.epa.gov/iris/subst/0364.htm. (Accessed: June 4, 2014).

EPA. 2004a. The Particle Pollution Report: Current Understanding of Air Quality and Emissions through 2003. EPA 454-R-04-002. Washington DC: U.S. Environmental Protection Agency. *Available at*: http://www.epa.gov/air/airtrends/aqtrnd04/pmreport03/report_2405.pdf. (Accessed: June 24, 2014).

EPA. 2004b. Oil Program Update: Special Issue Freshwater Spills Symposium 2004. Washington DC: U.S. Environmental Protection Agency. 8 pgs.

EPA. 2005. 2005 National-Scale Air Toxics Assessment. *Available at*: http://www.epa.gov/ttn/atw/nata2005/. (Accessed: June 4, 2014).

EPA. 2006. Air Quality Criteria for Ozone and Related Photochemical Oxidants (2006 Final). EPA/600/R-05/004aF-cF. *Available at*: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923. (Accessed: February 16, 2015).

EPA. 2007. Control of Hazardous Air Pollutants from Mobile Sources: Final Rule to Reduce Mobile Source Air Toxics. EPA 420-F-07-017. Washington DC: U.S. Environmental Protection Agency. *Available at*: http://www.epa.gov/otaq/regs/toxics/420f07017.pdf. (Accessed: June 24, 2014).

EPA. 2008. Effects of Acid Rain—Surface Waters and Aquatic Animals. *Available at*: http://www.epa.gov/acidrain/effects/surface_water.html. (Accessed: May 23, 2014).

EPA. 2009a. Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. U.S. Environmental Protection Agency, Office of Atmospheric Programs, Climate Change Division. Washington, DC.

EPA. 2009b. Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act **citing** IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY. Washington DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs, Climate Change Division.

EPA. 2009c. Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act **citing** NRC (National Research Council of the National Academies), Committee on Abrupt Change. Abrupt Climate Change, Inevitable Surprises. 2002. National Academy Press: Washington, DC. Washington DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs, Climate Change Division.

EPA. 2010a. Regulatory Impact Analysis (RIA) for the Reconsideration of the 2008 Ozone National Ambient Air Quality Standard (NAAQS). January 2010. *Available at*: http://www.epa.gov/ttn/ecas/regdata/RIAs/s1-supplemental_analysis_full.pdf. (Accessed: July 2, 2014).

EPA. 2010b. Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry: Final Report. Washington DC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (OAQPS), Air Benefit and Cost Group. August 2010. *Available at*: http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementfinalria.pdf. (Accessed: July 2, 2014).

EPA. 2010c. Final Regulatory Impact Analysis (RIA) for the NO2 National Ambient Air Quality Standards (NAAQS). Research Triangle Park, NC, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impact Division. Air Benefit-Cost Group.

EPA. 2010d. Toxicological Review of Formaldehyde-Inhalation Assessment: In Support of Summary Information on the Integrated Risk Information System (IRSI). External Review Draft. EPA/635/R-10/002A. Washington DC: U.S. Environmental Protection Agency.

EPA. 2011a. National Ambient Air Quality Standards (NAAQS). *Available at*: http://epa.gov/air/criteria.html. (Accessed: June 24, 2014).

EPA. 2011b. The 2011 National Emissions Inventory, Sector Summaries – Criteria and Hazardous Air Pollutants by 60 EIS emission sectors. Available: http://www.epa.gov/ttn/chief/net/2011inventory.html. (Accessed: June 25, 2014). .

EPA. 2012a. Office of Air and Radiation. Basic Information. *Available at*: http://epa.gov/air/basic.html. Accessed: June 24, 2014. Last Revised: July 16, 2012).

EPA. 2012b. Air Research. Near Roadway Research. *Available at*: http://www.epa.gov/airscience/air-highwayresearch.htm. Accessed: June 24, 2014. Last Revised: June 6, 2012.

EPA. 2012c. EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017–2025 Cars and Light Trucks. *Available at*: http://www.epa.gov/otaq/climate/documents/420f12051.pdf. (Accessed: June 4, 2014).

EPA. 2012d. Report to Congress on Black Carbon. March. *Available at*: http://www.epa.gov/blackcarbon/2012report/fullreport.pdf. (Accessed: June 30, 2014).

EPA. 2013a. 1970–2013 Average Annual Emissions, All Criteria Pollutants. MS Excel workbook. *Available at:* http://www.epa.gov/ttnchie1/trends/index.html/. (Accessed: June 24, 2014). Last Revised: February 17, 2014.

EPA. 2013b. The 2011 National Emissions Inventory, Sector Summaries, Mobile – On Road Vehicles. Version 1 released September 30. 1. *Available at*: http://www.epa.gov/ttn/chief/net/2011inventory.html. (Accessed: June 30, 2014).

EPA. 2013c. Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter. Research Triangle Park, NC, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impacts Division. *Available at*: http://www.epa.gov/ttn/ecas/regdata/RIAs/finalria.pdf. (Accessed: July 2, 2014)..

EPA. 2013d. Integrated Risk Information System Summaries: Benzene (CASRN 71-43-2). *Available at*: http://www.epa.gov/iris/subst/0276.htm. (Accessed: June 30, 2014).

EPA. 2013e. The Green Book Nonattainment Areas for Criteria Pollutants. *Available at*: http://www.epa.gov/airquality/greenbook/. (Accessed: June 13, 2014).

EPA. 2013f. Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors, U.S. Environmental Protection Agency. Table 2. January. *Available at*: http://www.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf. (Accessed: June 25, 2014).

EPA. 2014a. IRISTrack: Acetaldehyde. *Available at*: http://cfpub.epa.gov/ncea/iristrac/index.cfm. (Accessed: June 27, 2014).

EPA. 2014b. Integrated Risk Information System (IRIS): Notice of Integrated Risk Information System (IRIS). Notice of April 2014 Formaldehyde Workshop. *Available at*: http://www.epa.gov/iris/irisworkshops/fa/index.htm. (Accessed: June 30, 2014).

EPA. 2014c. Regulatory Announcement: EPA Sets Tier 3 Motor Vehicle Emission and Fuel Standards. U.S. Environmental Protection Agency. *Available at*: http://www.epa.gov/otaq/documents/tier3/420f14009.pdf. (Accessed: April 23, 2014).

EPA. 2014d. Technology Transfer Network, Clearinghouse for Inventories & Emissions Factors, 2011-based Modeling Platform. *Available at*: http://www.epa.gov/ttn/chief/emch/index.html. (Accessed: June 25, 2014).

EPA. 2014e. Guidelines for Preparing Economic Analyses. U.S. Environmental Protection Agency. National Center for Environmental Economics Office of Policy. Published December 2010. Updated May 2014. *Available at*: http://yosemite.epa.gov/ee/epa/eerm.nsf/vwan/ee-0568-50.pdf/$file/ee-0568-50.pdf. (Accessed: July 2, 2014).

EPA. 2015. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013. *Available at*: http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. (Accessed: April 22, 2015).

EPA, NHTSA (National Highway Transportation Safety Administration), and CARB (California Air and Resources Board). 2010. Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017–2025. *Available at*: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017+CAFE-GHG_Interim_TAR2.pdf. (Accessed: June 4, 2014).

European Union. 2005. Questions & Answers on Emissions Trading and National Allocation Plans. *Available at*: http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/05/84&format=HTML&aged=1&language=EN&guiLanguage=en. (Accessed: February 16, 2015).

European Union. 2014. European Union Emissions Trading System (EU ETS). *Available at*: http://ec.europa.eu/clima/policies/ets/index_en.htm. (Accessed: June 23, 2014).

Executive Office of the President. 2013. President's Climate Action Plan. *Available at*: http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf. (Accessed: July 8, 2014).

Executive Office of the President. 2014. FACT SHEET: Climate Action Plan—Strategy to Cut Methane Emissions. *Available at*: http://www.epa.gov/climatechange/Downloads/EPAactivities/EPA_Global_NonCO2_Projections_Dec2012.pdf. (Accessed: July 8, 2014).

FAA (Federal Aviation Administration). 2009. Fact Sheet: Commercial Aviation Alternative Fuels Initiative.

FAA. 2014. Environment and Energy Research & Development: Sustainable Alternative Jet Fuels.

Fabry, V. J., B. A. Seibel, R. A. Feely, and J. C. Orr. 2008. Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes. International Council for the Exploration of the Sea (ICES). *Journal of Marine Science: Journal du Conseil* 65(3):414–432.

Facanha C., and A. Horvath. 2007. Evaluation of Life-Cycle Air Emission Factors of Freight Transportation. *Environmental Science & Technology* 41(20):7138–7144.

Fahey, D. W., and M. I. Hegglin. 2010. Twenty Questions and Answers about the Ozone Layer: 2010 Update. Scientific Assessment of Ozone Depletion: 2010. World Meteorological Organization Global Ozone Research and Monitoring Project. Geneva, Switzerland. 10.

Fahey, D., et al. 2008a. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC, CCSP (U.S. Climate Change Science Program).

Fahey, D., et al. 2008b. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research **citing** Butchart, N., and A. A. Scaife. 2001. Removal of Chlorofluorocarbons by Increased Mass Exchange between the Stratosphere and the Troposphere in a Changing Climate. Nature 410(6830):799–802. U.S. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC, CCSP (U.S. Climate Change Science Program).

Fahey, D., et al. 2008c. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research **citing** Gillett, N. P., and D. W. J. Thompson. 2003. Simulation of Recent Southern Hemisphere Climate Change. Science 302(5643):273–275. U.S. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC, CCSP (U.S. Climate Change Science Program).

Fahey, D., et al. 2008d. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research **citing** Jonsson, A. I., J. de Grandpré, V. I. Fomichev, J. C. McConnell, and S. R. Beagley. 2004. Doubled CO2-induced Cooling in the Middle Atmosphere: Photochemical Analysis of the Ozone Radiative Feedback. Journal of Geographic

Research 109:D24103. U.S. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC, CCSP (U.S. Climate Change Science Program).

Fahey, D., et al. 2008e. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research **citing** Ramaswamy, V., and M. D. Schwarzkopf. 2002. Effects of Ozone and Well-mixed Gases on Annual-mean Stratospheric Temperature Trends. Geophysical Research Letters 29:2064. U.S. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC, CCSP (U.S. Climate Change Science Program).

Fahey, D., et al. 2008f. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research **citing** Thompson, D. W. J., and S. Solomon. 2002. Interpretation of Recent Southern Hemisphere Climate Change. *Science* 296(5569):895–899. U.S. Department of Commerce, NOAA's National Climatic Data Center. Asheville, NC, CCSP (U.S. Climate Change Science Program).

Fann, N., C.M. Fulcher, and B.J. Hubbell. 2009. The Influence of Location, Source, and Emission Type in Estimates of the Human Health Benefits of Reducing a Ton of Air Pollution. Air Quality, Atmosphere & Health 2(3):169-176. doi: 10.1007/s11869-009-0044-0. *Available at*: http://www.springerlink.com/content/1381522137744641/fulltext.pdf. (Accessed: February 16, 2015).

Feely, R. A., S.C. Doney, and S.R. Cooley. 2009. Ocean Acidification: Present Conditions and Future Changes in a High-CO2 World. *Oceanography* 22(4):37–47.

Fenga, W. and M.A. Figliozzia. 2012. Conventional vs Electric Commercial Vehicle fleets: A Case Study of Economic and Technological Factors Affecting the Competitiveness of Electric Commercial Vehicles in the USA. *Procedia—Social and Behavioral Sciences* 39(2012):702–711.

FHWA (Federal Highway Administration). 2012. Interim Guidance Update on Mobile Source Air Toxic Analysis in NEPA Documents. Memorandum dated December 6, 2012. *Available at*: http://www.fhwa.dot.gov/environment/air_quality/air_toxics/policy_and_guidance/aqintguidmem.cfm. (Accessed: June 24, 2014).

FHWA. 2013. Fact Sheet: Surface Transportation Program. Last Revised: September 12, 2013. *Available at*: http://www.fhwa.dot.gov/map21/factsheets/stp.cfm. (Accessed: June 5, 2014).

Finzi, A. C., A. T. Austin, E. E. Cleland, S. D. Frey, B. Z. Houlton, and M. D Wallenstein. 2011. Responses and Feedbacks of Coupled Biogeochemical Cycles to Climate Change: Examples from Terrestrial Ecosystems. *Frontiers in Ecology and the Environment* 9(1):61–67.

Fischbach, A. S., S. C. Amstrup, and D. C. Douglas. 2007. Landward and Eastward Shift of Alaskan Polar Bear Denning Associated with Recent Sea Ice Changes. *Polar Biology* 30(11):1395–1405.

Fischbeck, P. S., D. Gerard, B. McCoy, and J. Hyun. 2006. Using GIS to Explore Environmental Justice Issues: The Case of US Petroleum Refineries. Center for the Study and Improvement of Regulation: Carnegie Mellon University. 18 pgs.

Flanner, M.G., C.S. Zender, J.T. Randerson, and P.J. Rasch. 2007. Present-day Climate Forcing and Response from Black Carbon in Snow. *Journal of Geophysical Research: Atmospheres* (1984–2012) 112(D11):202.

Fleet Engineers. 2014. Air Slipper Side Skirts. *Available at*: http://fleetengineers.com/pdf/Air_Slipper_Side_Skirt.pdf. (Accessed: July 8, 2014).

Foster, J. R. 1991. Effects of Organic Chemicals in the Atmosphere on Terrestrial Plants. In: Ecological Exposure and Effects of Airborne Toxic Chemicals: An Overview. EPA/600/3-91/001. [T. J. Moser, J. R. Barker, and D. T. Tingey (eds.)]. U.S. Environmental Protection Agency: Corvallis, Oregon. *Available at*: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=91008ISW.txt. (Accessed: June 4, 2012).

FRA (Federal Railroad Administration). 2014. Rail Network Development. High Speed Intercity Passenger Rail (HSIPR) Program. *Available at*: https://www.fra.dot.gov/Page/P0134. (Accessed: June 13, 2014).

FracFocus. 2014. Regulations by State. *Available at*: http://www.fracfocus.org/regulations-state. (Accessed: June 5, 2014).

Franco-Suglia, S., A. Gryparis, A., and R.O. Wright. 2007. Association of Black Carbon with Cognition Among Children in a Prospective Birth Cohort Study. *American Journal of Epidemiology* 167(3):280–286. doi: 10.1093/aje/kwm308.

Frazier, A.G., H.F. Diaz, and T.W. Giambelluca. 2011. Rainfall in Hawaii: Spatial and Temporal Changes Since 1920. Abstract #GC21B-0900. American Geophysical Union, Fall Meeting 2011.

Freight Wing. 2014a. Freight Wing Gap Fairing, *Available at*: http://www.freightwing.com/gap_fairing.php. (Accessed: July 8, 2014).

Freight Wing. 2014b. Aeroflex Advanced Series. *Available at*: http://www.freightwing.com/aeroflex.php. (Accessed: July 8, 2014).

Frey, H.C. and P. Kuo. 2009. Real-World Energy Use and Emission Rates for Idling Long-Haul Trucks and Selected Idle Reduction Technologies. *Journal of the Air and Waste Management Association* 59(7):857–864.

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007a. Confronting Climate Change in the US Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment **citing** Ziska, L. H., P. R. Epstein, and C. A. Rogers. 2008. Climate Change, Aerobiology, and Public Health in the Northeast United States. Mitigation and Adaptation Strategies for Global Change. USC (Union of Concerned Scientists). Cambridge, MA.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007b. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment **citing** Ziska, L.H. and F.A. Caulfield. 2000. Rising Carbon Dioxide and Pollen Production of Common Ragweed, a Known Allergy-inducing Species: Implications for Public Health. Australian Journal of Plant Physiology 27:893–898. USC (Union of Concerned Scientists). Cambridge, MA. 145 pgs.

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007c. Confronting Climate Change in the US Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment **citing** Ziska Mohan, J. E., L. H. Ziska, W. H. Schlesinger, R. B. Thomas, R.

C. Sicher, K. George, and J. S. Clark. 2006. Biomass and Toxicity Responses of Poison Ivy (Toxicodendron radicans) to Elevated Atmospheric CO_2. *Proceedings National Academy of Sciences* 103(24):9086–9089.

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007d. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment **citing** Ziska Wayne, P., S. Foster, J. Connolly, F. Bazzaz, and P. Epstein. 2002. Production of Allergenic Pollen by Ragweed (Ambrosia artemisiifolia L.) Is Increased in CO2-enriched Atmospheres. Annals of Allergy, Asthma and Immunology 88:279–282. USC (Union of Concerned Scientists). Cambridge, MA. 145 pgs.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007e. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment **citing** Campbell-Lendrum, D., and R. E. Woodruff. 2006. Comparative Risk Assessment of the Burden of Disease from Climate Change. Environmental Health Perspectives 114(12):1935–1941. USC (Union of Concerned Scientists). Cambridge, MA. 145 pgs.

Frumhoff, P.C., J.J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007f. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment **citing** McMichael, A.J., R.E. Woodruff, and S. Hales. 2006. Climate Change and Human Health: Present and Future Risk. Lancet 367:859–869. USC (Union of Concerned Scientists). Cambridge, MA. 145 pgs.

Fussell, E., K. J. Curtis, and J. DeWaard. 2014. Recovery Migration to the City of New Orleans after Hurricane Katrina: A Migration Systems Approach. *Population and Environment* 35(3):305–322.

Gaines, L., and C. Brodrick Hartman. 2009. Energy Use and Emissions Comparison of Idling Reduction Options for Heavy-Duty Diesel Trucks. Paper No. 09-3395. Argonne National Laboratory. 90th Annual Meeting of the Transportation Research Board. Washington, DC.

Gaines, L., J. Sullivan, A. Burnham, and I. Belharouak. 2011. Life-Cycle Analysis for Lithium-Ion Battery Production and Recycling. Paper No. 11-3891. Argonne National Laboratory. 90th Annual Meeting of the Transportation Research Board. Washington, DC.

Galipeau-Belair, P., M. El-Gindy, S. Ghantae, D. Critchley, and S. A. Ramachandra. 2013. A Review of Side Underride Statistics and Protection Device Literature and Designs. *International Journal of Heavy Vehicle Systems* 20(4):361–374.

Galitsky, C. 2008. Energy Efficiency Improvement and Cost Saving Opportunities for the Vehicle Assembly Industry: An ENERGY STAR Guide for Energy and Plant Managers. Lawrence Berkeley National Laboratory. *Available at*: http://escholarship.org/uc/item/33x4p6p9. (Accessed: July 8, 2014).

GAO (U.S. Government Accountability Office). 2003. Alaska Native Villages: Most Are Affected by Flooding and Erosion but Few Qualify for Federal Assistance.

GAO (U.S. Government Accountability Office). 2009. Alaska Native Villages: Limited Progress Has Been Made on Relocating Villages Threatened by Flooding and Erosion. Government Accountability Office Report GAO-09-551, U.S. Government Accountability Office.

Gardner, A. S., G. Moholdt, J. G. Cogley, B. Wouters, A. A. Arendt, J. Wahr, E. Berthier, R. Hock, W. T. Pfeffer, G. Kaser, S. R. M. Ligtenberg, T. Bolch, M. J. Sharp, J. O. Hagen, M. R. van den Broeke, and F. Paul. 2013. A Reconciled Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009. *Science* 340(6134):852–857.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy (eds.). 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC.

Garshick, Eric, Francine Laden, Jaime E. Hart, Mary E. Davis, Ellen A. Eisen, and Thomas J. Smith. 2012. Lung cancer and elemental carbon exposure in trucking industry workers. *Environmental Health Perspectives* 120(9):1301-1306.

GCRP (U.S. Global Change Research Program). 2009. Global Climate Impacts in the United States. Cambridge, United Kingdom and New York, NY, USA. T. R. Karl, J. M. Melillo, and T.C. Peterson (eds.). Cambridge University Press: 196 pgs.

GCRP. 2009. Global Climate Change Impacts in the United States. Cambridge University Press. Cambridge, UK and New York, NY.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. Washington, DC.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ababneh, L. 2008. Bristlecone Pine Paleoclimatic Model for Archeological Patterns in the White Mountain of California. Quaternary International 188:59–78. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Abatzoglou, J. T., and C. A. Kolden. 2011. Climate Change in Western US Deserts: Potential for Increased Wildfire and Invasive Annual Grasses. Rangeland Ecology & Management 64:471–478. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Aeby, G., T. Work, D. Fenner, and E. Didonato. 2009. Coral and Crustose Coralline Algae Disease on the Reefs of American Samoa. Proceedings of the 11th International Coral Reef Symposium. Florida. Session 7:197–201. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Alessa, L., A. Kliskey, R. Busey, L. Hinzman, and D. White. 2008. Freshwater Vulnerabilities and Resilience on the Seward Peninsula: Integrating Multiple Dimensions of Landscape Change. Global Environmental Change 18:256–270. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Alexander, L. V., X. Zhang, T. C. Peterson, J. Caesar, B. Gleason, A. M. G. Klein Tank, M. Haylock, D. Collins, B. Trewin, F.Rahimzadeh,

A. Tagipour, K. Rupa Kumar, J. Revadekar, G. Griffiths, L. Vincent, D. B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, and J. L. Vazquez-Aguirre. 2006. Global Observed Changes in Daily Climate Extremes of Temperature and Precipitation. Journal of Geophysical Research 111:22. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Allison, E. H., M.-C. Badjeck, and K. Meinhold. 2011. Ch. 17: The Implications of Global Climate Change for Molluscan Aquaculture. In: Shellfish Aquaculture and the Environment. Wiley-Blackwell, pgs. 461–490. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Anticipating Ocean Acidification's Economic Consequences for Commercial Fisheries. Environmental Research Letters 4:8. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Antle, J. M., S. M. Capalbo, E. T. Elliott, and K. H. Paustian. 2004. Adaptation, Spatial Heterogeneity, and the Vulnerability of Agricultural Systems to Climate Change and CO2 Fertilization: An Integrated Assessment Approach. Climatic Change 64:289–315. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Arendt, A. A., K. A. Echelmeyer, W. D. Harrison, C. S. Lingle, and V. B. Valentine. 2002. Rapid Wastage of Alaska Glaciers and their Contribution to Rising Sea Level. Science 297:382–386. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Arendt, A. A., S. B. Luthcke, and R. Hock. 2009. Glacier Changes in Alaska: Can Mass-balance Models Explain GRACE Mascon Trends? Annals of Glaciology 50:148–154. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Avis, C. A., A. J. Weaver, and K. J. Meissner. 2011. Reduction in Areal Extent of High-latitude Wetlands in Response to Permafrost Thaw. Nature Geoscience 4:444–448. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Baldocchi, D., and S. Wong. 2008. Accumulated Winter Chill is Decreasing in the Fruit Growing Regions of California. Climatic Change 87:153–166. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Battisti, D. S., and R. L. Naylor. 2009. Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat. Science 323:240–244. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Baylis, M., and A. K. Githeko. 2006. The Effects of Climate Change on Infectious Diseases of Animals. Report for the Foresight Project on Detection of Infectious Diseases, Department of Trade and Industry. UK Government Foresight Project, Infectious Diseases: preparing for the future. Office of Science and Innovation. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Beach, R. H., C. Zhen, A. Thomson, R. M. Rejesus, P. Sinha, A. W. Lentz, D. V. Vedenov, and B. A. McCarl. 2010. Climate Change Impacts on Crop Insurance. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Berner, J., C. Furgal, P. Bjerregaard, M. Bradley, T. Curtis, E. D. Fabo, J. Hassi, W. Keatinge, S. Kvernmo, S. Nayha, H. Rintamaki, and J. Warren. 2005. Ch. 15: Human Health. In: Arctic Climate Impact Assessment. Cambridge University Press, pgs. 863–906. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Berthier, E., E. Schiefer, G. K. C. Clarke, B. Menounos, and F. Rémy. 2010. Contribution of Alaskan Glaciers to Sea-level Rise Derived from Satellite Imagery. Nature Geoscience 3:92–95. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bhatia, M. P., S. B. Das, K. Longnecker, M. A. Charette, and E. B. Kujawinski. 2010. Molecular Characterization of Dissolved Organic Matter Associated with the Greenland Ice Sheet. Geochimica et Cosmochimica Acta 74:3768–3784. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bieniek, P. A., J. E. Walsh, R. L. Thoman, and U. S. Bhatt. 2014. Using Climate Divisions to Analyze Variations and Trends in Alaska Temperature and Precipitation. Journal of Climate (27) 2800–2818. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bonfils, C., B. D. Santer, D. W. Pierce, H. G. Hidalgo, G. Bala, T. Das, T. P. Barnett, D. R. Cayan, C. Doutriaux, A. W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and Attribution of Temperature Changes in the Mountainous Western United States. Journal of Climate 21:6404–6424. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bradley, B. A., D. M. Blumenthal, R. Early, E. D. Grosholz, J. J. Lawler, L. P. Miller, C. J. B. Sorte, C. M. D'Antonio, J. M. Diez, J. S. Dukes, I. Ibanez, and J. D. Olden. 2012. Global Change, Global Trade, and the Next Wave of Plant Invasions.

Frontiers in Ecology and the Environment 10:20–28. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens, M. L. Floyd, J. Belnap, J. J. Anderson, O. B. Myers, and C. W. Meyer. 2005. Regional Vegetation Die-off In Response to Global-change-type Drought. Proceedings of the National Academy of Sciences 102:15144–15148. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bromirski, P. D., A. J. Miller, R. E. Flick, and G. Auad. 2011. Dynamical Suppression of Sea Level Rise Along the Pacific Coast of North America: Indications for Imminent Acceleration. Journal of Geophysical Research 116:C07005. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Brubaker, M., J. Berner, R. Chavan, and J. Warren. 2011. Climate Change and Health Effects in Northwest Alaska. Global Health Action 4:1–5. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** California Department of Water Resources. 2009. Ch. 5: Managing for an Uncertain Future. California Water Plan Update 2009. Integrated Water Management. Volume 1 – The Strategic Plan, State of California 5-1-5-36. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Campbell, J. L., L. E. Rustad, S. F. Christopher, C. T. Driscoll, I. J. Fernandez, P. M. Groffman, D. Houle, J. Kiekbusch, A. H. Magill, M. J. Mitchell, and S. V. Ollinger. 2009. Consequences of Climate Change for Biogeochemical Cycling in Forests of Northeastern North America. Canadian Journal of Forest Research 39:264–284. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cayan, D. R., A. L. Luers, G. Franco, M. Hanemann, B. Croes, and E. Vine. 2008. Overview of the California Climate Change Scenarios Project. Climatic Change 87:1–6. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov. 2010. Future Dryness in the Southwest US and the Hydrology of the Early 21st Century Drought. Proceedings of the National Academy of Sciences 107:21271–21276. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** CCSP. 2008b. Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources. Prepared by the U.S. Climate

Change Science Program and the Subcommittee on Global Change. U.S. Environmental Protection Agency. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** CCSP. 2007. The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Climate Change Science Program Synthesis and Assessment Product 2.2. Climate Change Science Program. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** CCSP. 2008. Weather and Climate Extremes in a Changing Climate – Regions of Focus – North America, Hawaii, Caribbean, and U.S. Pacific Islands. U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Vol. 3.3. Department of Commerce, NOAA's National Climatic Data Center. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Chen, I.-C., J. K. Hill, R. Ohlemüller, D. B. Roy, and C. D. Thomas. 2011. Rapid Range Shifts of Species Associated with High Levels of Climate Warming. Science 333:1024–1026. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cherry, J. E., S. Walker, N. Fresco, S. Trainor, and A. Tidwell. 2010. Impacts of Climate Change and Variability on Hydropower in Southeast Alaska: Planning for a Robust Energy Future. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Christensen, N., and D. P. Lettenmaier. 2006. A Multimodel Ensemble Approach to Assessment of Climate Change Impacts on the Hydrology and Water Resources of the Colorado River Basin. Hydrology and Earth System Sciences 3:3727–3770. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cochran, P., O. H. Huntington, C. Pungowiyi, S. Tom, F. S. Chapin, III, H. P. Huntington, N. G. Maynard, and S. F. Trainor. 2013. Indigenous Frameworks for Observing and Responding to Climate Change in Alaska. Climatic Change 120:557–567. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Colaizzi, P. D., P. H. Gowda, T. H. Marek, and D. O. Porter. 2009. Irrigation in the Texas High Plains: A Brief History and Potential Reductions in Demand. Journal of Irrigation and Drainage Engineering 58:257–274. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Coleman-Jensen, A., M. Nord, M. Andrews, and S. Carlson. 2012. Statistical Supplement to Household Food Security in the United

States in 2011. AP-058. U.S. Department of Agriculture. Economic Research Service. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cooley, H., E. Moore, M. Heberger, and L. Allen. 2012. Social Vulnerability to Climate Change in California. California Energy Commission. Pacific Institute. Oakland, CA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Davis, M. 2012. Appendix C. Alaska Forum on the Environment: Climate Change: Our Voices, Sharing Ways Forward. The United States National Climate Assessment – Alaska Technical Regional Report. U.S. Geological Survey Circular 1379. U. S. Geological Survey 121–128. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Derksen, C., and R. Brown. 2012. Spring Snow Cover Extent Reductions in the 2008–2012 Period Exceeding Climate Model Projections. Geophysical Research Letters 39:L19504. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dietze, M. C., and P. R. Moorcroft. 2011. Tree Mortality in the Eastern and Central United States: Patterns and Drivers. Global Change Biology 17:3312–3326. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** DOE. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. ORNL/TM-2011-224. U.S. Department of Energy, Office of the Biomass Program, Oak Ridge National Laboratory. Oak Ridge, TN. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Easterling, W. E. 2010. Guidelines for Adapting Agriculture to Cclimate Change. Handbook of Climate Change and Agroecosystems: Impacts, Adaptation, and Mitigation, ICP Series in Climate Change Impacts, Adaptation, and Mitigation – Vol. 1. Imperial College Press. 452 pgs. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** EIA. 2011. Annual Energy Outlook 2011. U.S. Energy Information Administration, Washington, DC. Washington DC: U.S. Global Change Research Program. Washington, DC.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** EPA. 2005. Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture. EPA 430-R-05-006. U.S. Environmental Protection Agency, Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** EPA. 2012. SAB Review of EPA's

Accounting Framework for Biogenic CO2 Emissions from Stationary Sources (September 2011). EPA-SAB-12-011, 81 pp., U.S. Environmental Protection Agency, Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ericksen, P. J., J. S. I. Ingram, and D. M. Liverman. 2009. Food Security and Global Environmental Change: Emerging Challenges. Environmental Science & Policy 12:373–377. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Euskirchen, E. S., A. D. McGuire, D. W. Kicklighter, Q. Zhuang, J. S. Clein, R. J. Dargaville, D. G. Dye, J. S. Kimball, K. C. McDonald, J. M. Melillo, V. E. Romanovsky, and N. V. Smith. 2006. Importance of Recent Shifts in Soil Thermal Dynamics on Growing Season Length, Productivity, and Carbon Sequestration in Terrestrial High-latitude Ecosystems. Global Change Biology 12:731–750. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Farley, E. V., Jr., J. M. Murphy, B. W. Wing, J. H. Moss, and A. Middleton. 2005. Distribution, Migration Pathways, and Size of Western Alaska Juvenile Salmon along the Eastern Bering Sea Shelf. Alaska Fishery Research Bulletin 11:15–26. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fay, F. H. 1982. Ecology and Biology of the Pacific Walrus, Odobenus rosmarus divergens Illiger. U.S. Department of the Interior, Fish and Wildlife Service. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fellman, J. B., R. G. M. Spencer, P. J. Hernes, R. T. Edwards, D. V. D'Amore, and E. Hood. 2010. The Impact of Glacier Runoff on the Biodegradability and Biochemical Composition of Terrigenous Dissolved Organic Matter in Near-shore Marine Ecosystems. Marine Chemistry 121:112–122. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** FERC and NAERC. 2012. Arizona-Southern California Outages on September 8, 2011: Causes and Recommendations. Federal Energy Regulatory Commission, North American Electric Reliability Corporation. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fischbach, A. S., D. H. Monson, and C. V. Jay. 2009. Enumeration of Pacific Walrus Carcasses on Beaches of the Chukchi Sea in Alaska Following a Mortality Event, September 2009. Open-File Report 2009-1291. U.S. Geological Survey. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gaines, S. D., B. Gaylord, and J. L. Largier. 2003. Avoiding Current Oversights in Marine Reserve Design. Ecological Applications 13:S32–S46. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Galloway McLean, K., A. Ramos-Costillo, T. Gross, S. Johnston, M. Vierros, and R. Noa. 2009. Report on the Indigenous Peoples' Global Summit on Climate Change. Darwin, Australia, United Nations University – Traditional Knowledge Initiative. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy (eds.). 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gershunov, A., D. R. Cayan, and S. F. Iacobellis. 2009. The Great 2006 Heat Wave over California and Nevada: Signal of an Increasing Trend. Journal of Climate 22:6181–6203. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gershunov, A., Z. Johnston, H. G. Margolis, and K. Guirguis. 2011. The California Heat Wave 2006 with Impacts on Statewide Medical Emergency: A Space-time Analysis. Geography Research Forum 31:6–31. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gleick, P. H. 2010. Roadmap for Sustainable Water Resources in Southwestern North America. Proceedings of the National Academy of Sciences 107:21300–21305. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Goldsmith, S. 2008. Understanding Alaska's Remote Rural Economy. UA Research Summary. Anchorage, AK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gonzalez, P., R. P. Neilson, J. M. Lenihan, and R. J. Drapek. 2010. Global Patterns in the Vulnerability of Ecosystems to Vegetation Shifts due to Climate Change. Global Ecology and Biogeography 19:755–768. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Graumlich, L. J. 1993. A 1000-year Record of Temperature and Precipitation in the Sierra Nevada. Quaternary Research 39:249–255. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hansen, J. E., and M. Sato. 2012. Paleoclimate Implications for Human-Made Climate Change. In: Climate Change. Inferences from Paleoclimate and Regional Aspects. Springer Vienna, pgs. 21–47. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hawkins, E., and R. Sutton. 2009. The Potential to Narrow Uncertainty in Regional Climate Predictions. Bulletin of the American Meteorological Society 90, 1095–1107. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Heberger, M., H. Cooley, P. Herrera, P. H. Gleick, and E. Moore. 2011. Potential Impacts of Increased Coastal Flooding in California due to Sea-level Rise. Climatic Change 109:229–249. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hidalgo, H. G., T. Das, M. D. Dettinger, D. R. Cayan, D. W. Pierce, T. P. Barnett, G. Bala, A. Mirin, A. W. Wood, C. Bonfils, B. D. Santer, and T. Nozawa. 2009. Detection and Attribution of Streamflow Timing Changes to Climate Change in the Western United States. Journal of Climate 22:3838–3855. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hood, E., J. Fellman, R. G. M. Spencer, P. J. Hernes, R. Edwards, D. D'Amore, and D. Scott. 2009. Glaciers as a Source of Ancient and Labile Organic Matter to the Marine Environment. Nature 462:1044–1047. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hu, Q., A. Weiss, S. Feng, and P. S. Baenziger. 2005. Earlier Winter Wheat Heading Dates and Warmer Spring in the U.S. Great Plains. Agricultural and Forest Meteorology 135:284–290. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hunt, G. L., Jr., K. O. Coyle, L. B. Eisner, E. V. Farley, R. A. Heintz, F. Mueter, J. M. Napp, J. E. Overland, P. H. Ressler, S. Salo, and P. J. Stabeno. 2011. Climate Impacts on Eastern Bering Sea Foodwebs: A Synthesis of New Data and an Assessment of the Oscillating Control Hypothesis. ICES Journal of Marine Science 68:1230–1243. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hunter, C. M., H. Caswell, M. C. Runge, E. V. Regehr, S. C. Amstrup, and I. Stirling. 2010. Climate Change Threatens Polar Bear Populations: A Stochastic Demographic Analysis. Ecology 91:2883–2897. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jackson, L. E., S. M. Wheeler, A. D. Hollander, A. T. O'Geen, B. S. Orlove, J. Six, D. A. Sumner, F. Santos-Martin, J. B. Kramer, W. R. Horwath, R. E. Howitt, and T. P. Tomich. 2011. Case Study on Potential Agricultural Responses to Climate Change in a California Landscape. Climatic Change 109:407–427. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jackson, L., V. R. Haden, S. M. Wheeler, A. D. Hollander, J. Perlman, T. O'Geen, V. K. Mehta, V. Clark, and J. Williams. 2012. Vulnerability and Adaptation to Climate Change in California Agriculture. A White Paper from the California Energy Commission's California Climate Change Center (PIER Program). CEC-500-2012-031. Sacramento, California Energy Commission. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jacob, T., J. Wahr, W. T. Pfeffer, and S. Swenson. 2012. Recent Contributions of Glaciers and Ice Caps to Sea Level Rise. Nature 482:514–518. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jafarov, E. E., S. S. Marchenko, and V. E. Romanovsky. 2012. Numerical Modeling of Permafrost Dynamics in Alaska Using a High Spatial Resolution Dataset. The Cryosphere Discussions 6:89–124. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jones, B. M., C. D. Arp, K. M. Hinkel, R. A. Beck, J. A. Schmutz, and B. Winston. 2009. Arctic Lake Physical Processes and Regimes with Implications for Winter Water Availability and Management in the National Petroleum Reserve Alaska. Environmental Management 43:1071–1084. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jorgenson, T., K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones. 2008. Permafrost characteristics of Alaska. Extended Abstracts of the Ninth International Conference on Permafrost, June 29–July 3. 2008. University of Alaska Fairbanks, pgs. 121–123. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kaser, G., J. G. Cogley, M. B. Dyurgerov, M. F. Meier, and A. Ohmura. 2006. Mass Balance of Glaciers and Ice Caps: Consensus Estimates for 1961–2004. Geophysical Research Letters 33:L19501. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Klein, E., E. E. Berg, and R. Dial. 2005. Wetland Drying and Succession Across the Kenai Peninsula Lowlands, South-central Alaska.

Canadian Journal of Forest Research 35:1931–1941. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kodra, E., K. Steinhaeuser, and A. R. Ganguly. 2011. Persisting Cold Extremes under 21st-century Warming Scenarios. Geophysical Research Letters 38:L08705. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. Part 5. Climate of the Southwest U.S. NOAA Technical Report NESDIS 142-5. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, M.C. Kruk, D.P. Thomas, M. Shulski, N. Umphlett, K. Hubbard, K. Robbins, L. Romolo, A. Akyuz, T. Pathak, T. Bergantino, and J.G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains, NOAA Technical Report NESDIS 142-4. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Larsen, C. F., R. J. Motyka, A. A. Arendt, K. A. Echelmeyer, and P. E. Geissler. 2007. Glacier Changes in Southeast Alaska and Northwest British Columbia and Contribution to Sea Level Rise. Journal of Geophysical Research 112:F01007. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Larsen, P. H., S. Goldsmith, O. Smith, M. L. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor. 2008. Estimating Future Costs for Alaska Public Infrastructure at Risk from Climate Change. Global Environmental Change 18:442–457. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Leask, K., M. Killorin, and S. Martin. 2001. Trends in Alaska's People and Economy. Institute of Social and Economic Research. University of Alaska. Anchorage, AK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Litschert, S. E., T. C. Brown, and D. M. Theobald. 2012. Historic and Future Extent of Wildfires in the Southern Rockies Ecoregion, USA. Forest Ecology and Management 269:124–133. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Littell, J. S., D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. Climate and Wildfire Area Burned in Western US Ecoprovinces, 1916–2003. Ecological Applications 19:1003–1021. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lobell, D. B., C. B. Field, K. N. Cahill, and C. Bonfils. 2006. Impacts of Future Climate Change on California Perennial Crop Yields: Model Projections with Climate and Crop Uncertainties. Agricultural and Forest Meteorology 141:208–218. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Loeng, H., K. Brander, E. Carmack, S. Denisenko, K. Drinkwater, B. Hansen, K. Kovacs, P. Livingston, F. McLaughlin, and E. Sakshaug. 2005. Ch. 9: Marine Systems. In: Arctic Climate Impact Assessment. Cambridge University Press, pgs. 453–538. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Longstreth, J. 1999. Public Health Consequences of Global Climate Change in the United States: Some Regions May Suffer Disproportionately. Environmental Health Perspectives 107:169–179. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Luthcke, S. B., A. A. Arendt, D. D. Rowlands, J. J. McCarthy, and C. F. Larsen. 2008. Recent Glacier Mass Changes in the Gulf of Alaska Region from GRACE Mascon Solutions. Journal of Glaciology 54:767–777. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Maier, J. A. K., J. M. Ver Hoef, A. D. McGuire, R. T. Bowyer, L. Saperstein, and H. A. Maier. 2005. Distribution and Density of Moose in Relation to Landscape Characteristics: Effects of Scale. Canadian Journal of Forest Research 35:2233–2243. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Markon, C. J., S. F. Trainor, and F. S. Chapin, III, Eds. 2012. The United States National Climate Assessment – Alaska Technical Regional Report. U.S. Geological Survey Circular 1379. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Marlon, J. R., P. J. Bartlein, D. G. Gavin, C. J. Long, R. S. Anderson, C. E. Briles, K. J. Brown, D. Colombaroli, D. J. Hallett, M. J. Power, E. A. Scharf, and M. K. Walsh. 2012. Long-term Perspective on Wildfires in the Western USA. Proceedings of the National Academy of Sciences 109:E535-E543. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Maslowski, W., J. Clement Kinney, M. Higgins, and A. Roberts. 2012. The Future of Arctic Sea Ice. Annual Review of Earth and Planetary Sciences 40:625–654. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McLaughlin, J. A., A. DePaola, C. A.

Bopp, K. A. Martinek, N. P. Napolilli, C. G. Allison, S. L. Murray, E. C. Thompson, M. M. Bird, and J. P. Middaugh. 2005. Outbreak of Vibrio Parahaemolyticus Gastroenteritis Associated with Alaskan Oysters. New England Journal of Medicine 353:1463–1470. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Medina, J. 2011. Human Error Investigated in California Blackout's Spread to Six Million. The New York Times. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Millar, C. I., J. C. King, R. D. Westfall, H. A. Alden, and D. L. Delany, 2006: Late Holocene Forest Dynamics, Volcanism, and Climate Change at Whitewing Mountain and San Joaquin Ridge, Mono County, Sierra Nevada, CA, USA. Quaternary Research 66:273–287. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Moritz, M. A., M. A. Parisien, E. Batllori, M. A. Krawchuk, J. Van Dorn, D. J. Ganz, and K. Hayhoe. 2012. Climate Change and Disruptions to Global Fire Activity. Ecosphere 3:1–22. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Nardone, A., B. Ronchi, N. Lacetera, M. S. Ranieri, and U. Bernabucci. 2010. Effects of Climate Change on Animal Production and Sustainability of Livestock Systems. Livestock Science 130:57–69. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NRC. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Research Council, Committee on Sea Level Rise in California, Oregon, Washington, Board on Earth Sciences Resources, Ocean Studies Board, Division on Earth Life Studies The National Academies Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NWS. 2012. Weather Fatalities. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ostro, B., S. Rauch, and S. Green. 2011. Quantifying the Health Impacts of Future Changes in Temperature in California. Environmental Research 111:1258–1264. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Parmesan, C. 2007. Influences of Species, Latitudes and Methodologies on Estimates of Phenological Response to Global Warming. Global Change Biology 13:1860–1872. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Patz, J. A., S. J. Vavrus, C. K. Uejio, and S. L. McLellan. 2008. Climate Change and Waterborne Disease Risk in the Great Lakes Region of the US. American Journal of Preventive Medicine 35:451–458. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Peng, R. D., J. F. Bobb, C. Tebaldi, L. McDaniel, M. L. Bell, and F. Dominici. 2011. Toward a Quantitative Estimate of Future Heat Wave Mortality under Global Climate Change. Environmental Health Perspectives 119:701–706. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pierce, D. W., T. P. Barnett, H. G. Hidalgo, T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. R. Cayan, A. Mirin, A. W. Wood, and T. Nozawa. 2008. Attribution of Declining Western US Snowpack to Human Effects. Journal of Climate 21:6425–6444. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Prasad, A. M., L. R. Iverson, S. Matthews, and M. Peters. 2007. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [Database]. U.S. Department of Agriculture, Forest Service, Northern Research Station. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pryor, S. C., and R. J. Barthelmie. 2013. Ch. 2: The Midwestern United States: Socio-economic Context and Physical Climate. In: Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation. Indiana University Press, pgs. 12–47. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pryor, S. C., K. E. Kunkel, and J. T. Schoof. 2009. Ch. 9: Did Precipitation Regimes Change during the Twentieth Century? In: Understanding Climate Change: Climate Variability, Predictability and Change in the Midwestern United States, Indiana University Press, pgs. 100–112. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pryor, S. C., R. J. Barthelmie, and J. T. Schoof. 2013. High-resolution Projections of Climate Impacts for the Midwestern USA. Climate Research 56:61–79. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Purkey, D. R., B. Joyce, S. Vicuna, M. W. Hanemann, L. L. Dale, D. Yates, and J. A. Dracup. 2008. Robust Analysis of Future Climate Change Impacts on Water for Agriculture and Other Sectors: A Case Study in the Sacramento Valley. Climatic Change 87:109–122. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ray, A. J., J. J. Barsugli, K. B. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall, and R. S. Webb. 2008. Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation. Colorado Water Conservation Board. University of Colorado, Boulder, CO. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Romanovsky, V. E., S. L. Smith, H. H. Christiansen, N. I. Shiklomanov, D. S. Drozdov, N. G. Oberman, A. L. Kholodov, and S. S. Marchenko. 2011. Permafrost. Arctic Report Card 2011:139–147. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rosenzweig, C., F. N. Tubiello, R. Goldberg, E. Mills, and J. Bloomfield. 2002. Increased Crop Damage in the US from Excess Precipitation under Climate Change. Global Environmental Change 12:197–202. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Salzer, M. W., and K. F. Kipfmueller, 2005: Reconstructed Temperature and Precipitation on a Millennial Timescale from Tree-rings in the Southern Colorado Plateau, USA. Climatic Change 70:465–487. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Salzer, M. W., M. K. Hughes, A. G. Bunn, and K. F. Kipfmueller. 2009. Recent Unprecedented Tree-ring Growth in Bristlecone Pine at the Highest Elevations and Possible Causes. Proceedings of the National Academy of Sciences 106:20348–20353. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Samson, F. B., F. L. Knopf, and W. R. Ostlie. 2004. Great Plains Ecosystems: Past, Present, and Future. Wildlife Society Bulletin 32:6–15. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schoof, J. T. 2013. Ch. 11: Historical and projected changes in human heat stress in the Midwestern United States. In: Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation, S. C. Pryor (ed.), Indiana University Press, pgs. 146–157. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schoof, J. T., S. C. Pryor, and J. Suprenant. 2010. Development of Daily Precipitation Projections for the United States Based on Probabilistic Downscaling. Journal of Geophysical Research 115:1–13. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** SFBCDC. 2011. Living with a Rising Bay:

Vulnerability and Adaptation in San Francisco Bay and on its Shoreline. San Francisco Bay Conservation and Development Commission. San Francisco, CA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sheridan, S. C., C. C. Lee, M. J. Allen, and L. S. Kalkstein. 2012. Future Heat Vulnerability in California, Part I: Projecting Future Weather Types and Heat Events. Climatic Change 115:291–309. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sheridan, S. C., M. J. Allen, C. C. Lee, and L. S. Kalkstein. 2012. Future Heat Vulnerability in California, Part II: Projecting Future Heat-related Mortality. Climatic Change 115:311–326. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sheridan, S., C. Lee, M. Allen, and L. Kalkstein. 2011. A Spatial Synoptic Classification Approach to Projected Heat Vulnerability in California under Future Climate Change Scenarios. Final Report to the California Air Resources Board. Research Contract 07-304. California Air Resources Board and the California Environmental Protection Agency. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stevens, M. B., J. F. González-Rouco, and H. Beltrami, 2008: North American Climate of the Last Millennium: Underground Temperatures and Model Comparison. Journal of Geophysical Research 113:F01008. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Swetnam, T. W. 1993. Fire History and Climate Change in Giant Sequoia Groves. Science 262:885–889. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Swetnam, T. W., C. H. Baisan, A. C. Caprio, P. M. Brown, R. Touchan, R. S. Anderson, and D. J. Hallett. 2009. Multi-millennial Fire History of the Giant Forest, Sequoia National Park, California, USA. Fire Ecology 5:120–150. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Taylor, A. H., and A. E. Scholl. 2012. Climatic and Human Influences on Fire Regimes in Mixed Conifer Forests in Yosemite National Park, USA. Forest Ecology and Management 267:144–156. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Trouet, V., A. H. Taylor, E. R. Wahl, C. N.

Skinner, and S. L. Stephens. 2010. Fire-climate Interactions in the American West since 1400 CE. Geophysical Research Letters 37:L04702. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** U.S. Census Bureau. 2010. Census Urban and Rural Classification and Urban Area Criteria. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** USDA (U.S. Department of Agriculture). 2012. Atlas of Rural and Small-Town America. U.S. Department of Agriculture, Economic Research Service. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Westerling, A. L., M. G. Turner, E. A. H. Smithwick, W. H. Romme, and M. G. Ryan. 2011. Continued Warming Could Transform Greater Yellowstone Fire Regimes by mid-21st Century. Proceedings of the National Academy of Sciences 108:13165–13170. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Winder, M., and D. E. Schindler. 2004. Climate Change Uncouples Trophic Interactions in an Aquatic Ecosystem. Ecology 85:2100–2106. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** WSDOT. 2011. Climate Impacts Vulnerability Assessment. Washington State Department of Transportation. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Beckage, B., B. Osborne, D. G. Gavin, C. Pucko, T. Siccama, and T. Perkins. 2008. A Rapid Upward Shift of a Forest Ecotone during 40 Years of Warming in the Green Mountains of Vermont. Proceedings of the National Academy of Sciences 105:4197–4202. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Blake, E. S., T. B. Kimberlain, R. J. Berg, J. P. Cangialosi, and J. L. Beven, II. 2013. Tropical Cyclone Report: Hurricane Sandy. National Oceanic and Atmospheric Administration, National Hurricane Center. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Butler, C. J. 2003. The Disproportionate Effect of Global Warming on the Arrival Dates of Short-distance Migratory Birds in North America. Ibis 145:484–495. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Church, J. A., P. L. Woodworth, T.

Aarup, and W. S. Wilson. 2010. Understanding Sea-Level Rise and Variability. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** DOT. 2008. The Potential Impacts of Global Sea Level Rise on Transportation Infrastructure – Part 1: Methodology. Center for Climate Change and Environmental Forecasting, U.S. Department of Transportation. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fogarty, M., L. Incze, K. Hayhoe, D. Mountain, and J. Manning. 2008. Potential Climate Change Impacts on Atlantic Cod (Gadus morhua) off the Northeastern USA. Mitigation and Adaptation Strategies for Global Change 13:453–466. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Francis, J. A., and S. J. Vavrus. 2012. Evidence Linking Arctic Amplification to Extreme Weather in Mid-latitudes. Geophysical Research Letters 39:L06801. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007. Ch. 3: Marine impacts. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment (NECIA), Union of Concerned Scientists, pgs. 39–46. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hayhoe, K., C. P. Wake, T. G. Huntington, L. Luo, M. D. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T. Troy, and D. Wolfe. 2007. Past and Future Changes in Climate and Hydrological Indicators in the US Northeast. Climate Dynamics 28:381–407. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Horton, R. M., V. Gornitz, D. A. Bader, A. C. Ruane, R. Goldberg, and C. Rosenzweig. 2011. Climate Hazard Assessment for Stakeholder Adaptation Planning in New York City. Journal of Applied Meteorology and Climatology 50:2247–2266. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kirshen, P., C. Watson, E. Douglas, A. Gontz, J. Lee, and Y. Tian. 2008. Coastal flooding in the Northeastern United States due to Climate Change. Mitigation and Adaptation Strategies for Global Change 13:437–451. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, J. Rennells, A. DeGaetano, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 1. Climate of the Northeast U.S.

NOAA Technical Report NESDIS 142-1. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kuntz, J., and R. Murray. 2009. Predictability of Swimming Prohibitions by Observational Parameters: A Proactive Public Health Policy, Stamford, Connecticut, 1989–2004. Journal of Environmental Health 72:17–22. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Li, T., R. M. Horton, and P. L. Kinney. 2013. Projections of Seasonal Patterns in Temperature-related Deaths for Manhattan, New York. Nature Climate Change 3:717–721. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Liu, J., J. A. Curry, H. Wang, M. Song, and R. M. Horton. 2012. Impact of Declining Arctic Sea Ice on Winter Snowfall. Proceedings of the National Academy of Sciences 109:4074–4079. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Maryland Port Administration. 2008. The Economic Impacts of the Port of Baltimore. Martin Associates. Lancaster, PA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mohan, J. E., R. M. Cox, and L. R. Iverson. 2009. Composition and Carbon Dynamics of Forests in Northeastern North America in a Future, Warmer World. Canadian Journal of Forest Research 39:213–230. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NOAA. 2013a. Sea Level Trends. National Oceanic and Atmospheric Administration, National Ocean Service. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ahern, M., R.S. Kovats, P. Wilkinson, R. Few, and F. Matthies. 2005. Global Health Impacts of Floods: Epidemiologic Evidence. Epidemiologic Reviews 27:36–46. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Anderson, G.B., J.R. Krall, R.D. Peng, and M.L. Bell. 2012. Is the Relation Between Ozone and Mortality Confounded by Chemical Components of Particulate Matter? Analysis of 7 Components in 57 US Communities. American Journal of Epidemiology 176:726–732. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Arctic Council. 2009. Arctic Marine Shipping Assessment Report 2009. Arctic Council, Norwegian Chairmanship 2006–2009. Tromsø, Norway. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Aultman-Hall, L., D. Lane, and R. R. Lambert. 2009. Assessing Impact of Weather and Season on Pedestrian Traffic Volumes. Transportation Research Record: Journal of the Transportation Research Board 2140:35–43. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ball, M., C. Barnhart, M. Dresner, M. Hansen, K. Neels, A. Odoni, E. Peterson, L. Sherry, A. A. Trani, and B. Zou. 2010. Total Delay Impact Study: A Comprehensive Assessment of the Costs and Impacts of Flight Delay in the United States. NEXTOR. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Basu, R., and J.M. Samet. 2002. Relation Between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence. Epidemiologic Reviews 24:190–202. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Basu. 2010. The Effects of Temperature and Use of Air Conditioning on Hospitalizations. American Journal of Epidemiology 172(9):1053–1061. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bates, K. A., and R. S. Swan. 2007. Through the Eye of Katrina: Social Justice in the United States. Carolina Academic Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bouchama, A., M. Dehbi, G. Mohamed, F. Matthies, M. Shoukri, and B. Menne. 2007. Prognostic Factors in Heat Wave Related Deaths: A Meta-analysis. Archives of Internal Medicine 167:2170–2176. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bulbena, A., L. Sperry, and J. Cunillera. 2006. Psychiatric Effects of Heat Waves. Psychiatric Services 57:1519–1519. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cambridge Systematics Inc., and Texas Transportation Institute. 2005. Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation. U.S. Department of Transportation, Federal Highway Administration. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Centers for Disease Control. 2012. Rocky Mountain Spotted Fever. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Centers for Disease Control. 2013. Interactive Lyme Disease Map. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Chokshi, D.A., and T.A. Farley. 2012. The Cost-effectiveness of Environmental Approaches to Disease Prevention. New England Journal of Medicine 367:295–297. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Degallier, N., C. Favier, C. Menkes, M. Lengaigne, W. M. Ramalho, R. Souza, J. Servain, and J.P. Boulanger. 2010. Toward an Early Warning System for Dengue Prevention: Modeling Climate Impact on Dengue Transmission. Climatic Change 98:581–592. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Deisenhammer, E. A. 2003. Weather and Suicide: The Present State of Knowledge on the Association of Meteorological Factors with Suicidal Behaviour. Acta Psychiatrica Scandinavica 108:402–409. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Delgado, J. A., P. M. Groffman, M. A. Nearing, T. Goddard, D. Reicosky, R. Lal, N. R. Kitchen, C. W. Rice, D. Towery, and P. Salon. 2011. Conservation Practices to Mitigate and Adapt to Climate Change. Journal of Soil and Water Conservation 66:118A–129A. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dennekamp, M., and M. Carey. 2010. Air Quality and Chronic Disease: Why Action on Climate Change is Also Good for Health. New South Wales Public Health Bulletin 21:115–121. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Diuk-Wasser, M. A., G. Vourc'h, P. Cislo, A. G. Hoen, F. Melton, S. A. Hamer, M. Rowland, R. Cortinas, G. J. Hickling, J. I. Tsao, A. G. Barbour, U. Kitron, J. Piesman, and D. Fish. 2010. Field and Climate-based Model for Predicting the Density of Host-seeking Nymphal Ixodes Scapularis, An Important Vector of Tick-borne Disease Agents in the Eastern United States. Global Ecology and Biogeography 19:504–514. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** DOT. 2010. Freight Analysis Framework (version 3) Data Tabulation Tool, Total Flows. U.S. Department of Transportation. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ellis, J., D. Fisher, T. Longstaff, L. Pesante, and R. Pethia. 1997. The Report of the President's Commission on Critical Infrastructure Protection. The President's Commission on Critical Infrastructure Protection. Carnegie Mellon University. Pittsburgh, PA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Emberlin, J., M. Detandt, R. Gehrig, S. Jaeger, N. Nolard, and A. Rantio-Lehtimaki. 2002. Responses in the Start of Betula (birch) Pollen Seasons to Recent Changes in Spring Temperatures Across Europe. International Journal of Biometeorology 46:159–170. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** EPA. 2012a. EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017–2025 Cars and Light Trucks. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** ERS. 2012. Economic Research Service, U.S. Department of Agriculture. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** FAA. 2012. Federal Aviation Administration: U.S. & Territories Airport Lookup. Federal Aviation Administration. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** FAO. 2011. The State of Food Insecurity in the World – How Does International Price Volatility Affect Domestic Economies and Food Security? Food and Agriculture Organization of the United Nations, Rome, Italy. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fewtrell, L., and D. Kay. 2008. An Attempt to Quantify the Health Impacts of Flooding in the UK using an Urban Case Study. Public Health 122:446–451. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fisk, W. J., Q. Lei-Gomez, and M. J. Mendell. 2007. Meta-analyses of the Associations of Respiratory Health Effects with Dampness and Mold in Homes. Indoor Air 17:284–296. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Galea, S., C. R. Brewin, M. Gruber, R. T. Jones, D. W. King, L. A. King, R. J. McNally, R. J. Ursano, M. Petukhova, and R. C. Kessler. 2007. Exposure to Hurricane-related Stressors and Mental illness after Hurricane Katrina. Archives of General Psychiatry 64:1427–1434. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gaughan, J., N. Lacetera, S. E. Valtorta, H. H. Khalifa, L. Hahn, and T. Mader. 2009. Ch. 7: Response of Domestic Animals to Climate Challenges. In: Biometeorolog y for Adaptation to Climate Variability and Change. Springer Netherlands, pgs. 131–170. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gill, S. K., R. Wright, J. G. Titus, R. Kafalenos, and K. Wright. 2009. Ch. 7: Population, Land Use, and Infrastructure. Coastal Sensitivity to Sea Level Rise: A Focus on the Mid-Atlantic Region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research, U.S. Environmental Protection Agency. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Godfray, H. C. J., I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, N. Nisbett, J. Pretty, S. Robinson, C. Toulmin, and R. Whiteley. 2010. The Future of the Global Food System. Philosophical Transactions of the Royal Society B. Biological Sciences 365:2769–2777. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Goetz, S. J., B. Bond-Lamberty, B. E. Law, J. A. Hicke, C. Huang, R. A. Houghton, S. McNulty, T. O'Halloran, M. Harmon, A. J. H. Meddens, E. M. Pfeifer, D. Mildrexler, and E. S. Kasischke. 2012. Observations and Assessment of Forest Carbon Dynamics Following Disturbance in North America. Journal of Geophysical Research 117:G02022. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gong, H., A. T. DeGaetano and L. C. Harrington. 2011. Climate-based Models for West Nile Culex Mosquito Vectors in the Northeastern U.S. International Journal of Biometeorology 55:435–446. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Guo, Z., N. H. M. Wilson, and A. Rahbee. 2007. Impact of Weather on Transit Ridership in Chicago, Illinois. Transportation Research Record: Journal of the Transportation Research Board 2034:3–10. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gutierrez, M. H. Hayden, J. L. R. Lopez, M. Fournier, A. R. Trujillo, R. Burton, J. M. Brunkard, L. Anaya-Lopez, A. A. Banicki, P. K. Morales, B. Smith, J. L. Muñoz, and S. H. Waterman. 2008. Epidemic Dengue and Dengue Hemorrhagic Fever at the Texas–Mexico Border: Results of a Household-based Seroepidemiologic Survey, December 2005. The American Journal of Tropical Medicine and Hygiene 78:364–369. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Haines, A., A. J. McMichael, K. R. Smith,

I. Roberts, J. Woodcock, A. Markandya, B. G. Armstrong, D. Campbell-Lendrum, A. D. Dangour, M. Davies, N. Bruce, C. Tonne, M. Barrett, and P. Wilkinson. 2009. Public Health Benefits of Strategies to Reduce Greenhouse-gas Emissions: Overview and Implications for Policy Makers. The Lancet 374:2104–2114. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hansen, A., P. Bi, M. Nitschke, P. Ryan, D. Pisaniello, and G. Tucker. 2008. The Effect of Heat Waves on Mental Health in a Temperate Australian City. Environmental Health Perspectives 116:1369–1375. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Harper, S. L., V. L. Edge, C. J. Schuster-Wallace, O. Berke, and S. A. McEwen. 2011. Weather, Water Quality and Infectious Gastrointestinal Illness in Two Inuit Communities in Nunatsiavut, Canada: Potential Implications for Climate Change. Ecohealth 8:93–108. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hibbard, P. J. 2006. US Energy Infrastructure Vulnerability: Lessons from the Gulf Coast Hurricanes. National Commission on Energy Policy, Analysis Group. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hodges, T. 2011. Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation. Federal Transit Administration, Office of Research, Demonstration and Innovation, U.S. Department of Transportation. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hutson, S. S., N. L. Barber, J. F. Kenny, K. S. Linsey, D. S. Lumia, and M. A. Maupin. 2004. Estimate Use of Water in the United States in 2000. U.S. Geological Survey Circular 1268:46. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Institute of Medicine. 2011. Climate Change, the Indoor Environment, and Health. National Academies Press. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** IPCC. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jackson, L. E., F. Santos-Martin, A. D. Hollander, W. R. Horwath, R. E. Howitt, J. B. Kramer, A. T. O'Geen, B. S. Orlove, J. W. Six, S. K. Sokolow, D. A. Sumner, T. P. Tomich, and S. M. Wheeler. 2009. Potential for Adaptation to Climate Change in an Agricultural Landscape in the Central Valley of California. Publication number: CEC-

500-2009-044-F. California Energy Commission, PIER Energy-Related Environmental Research Program. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Janetos, A., L. Hansen, D. Inouye, B. P. Kelly, L. Meyerson, B. Peterson, and R. Shaw. 2008. Ch. 5: Biodiversity. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. A report by the U.S. Climate Change Science Program and the subcommittee on Global Change Research. U.S. Department of Agriculture. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Johansson, M. A., D. A. T. Cummings, and G. E. Glass. 2009. Multiyear Climate Variability and Dengue—El Niño Southern Oscillation, Weather, and Dengue Incidence in Puerto Rico, Mexico, and Thailand: A Longitudinal Data Analysis. PLoS Medicine 6:e1000168. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jury, M. R. 2008. Climate Influence on Dengue Epidemics in Puerto Rico. International Journal of Environmental Health Research 18:323–334. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Karl, T. R., B. E. Gleason, M. J. Menne, J. R. McMahon, R. R. Heim, Jr., M. J. Brewer, K. E. Kunkel, D. S. Arndt, J. L. Privette, J. J. Bates, P. Y. Groisman, and D. R. Easterling. 2012. U.S. Temperature and Drought: Recent Anomalies and Trends. Eos, Transactions, American Geophysical Union 93:473–474. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Karuk Tribe. 2010. Department of Natural Resources Eco-Cultural Resource Management Plan. Karuk Tribe of California, Department of Natural Resources. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Keesing, F., J. Brunner, S. Duerr, M. Killilea, K. LoGiudice, K. Schmidt, H. Vuong, and R.S. Ostfeld. 2009. Hosts as Ecological Traps for the Vector of Lyme Disease. Proceedings of the Royal Society B: Biological Sciences 276:3911–3919. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kessler, R. C., S. Galea, M. J. Gruber, N. A. Sampson, R. J. Ursano, and S. Wessely. 2008. Trends in Mental Illness and Suicidality after Hurricane Katrina. Molecular Psychiatry 13:374–384. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Khelifa, A., L. Garrow, M. Higgins, and M. Meyer. 2013. Impacts of Climate Change on Scour-vulnerable Bridges: Assessment Based on

HYRISK. Journal of Infrastructure Systems 19:138–146. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kinney, P. L. 2008. Climate Change, Air Quality, and Human Health. American Journal of Preventive Medicine 35:459–467. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kirshen, P., M. Ruth, and W. Anderson. 2008. Interdependencies of Urban Climate Change Impacts and Adaptation Strategies: A Case Study of Metropolitan Boston USA. Climatic Change 86:105–122. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Koleva, N. G., and U. A. Schneider. 2009. The Impact of Climate Change on the External Cost of Pesticide Applications in US Agriculture. International Journal of Agricultural Sustainability 7:203–216. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kolivras, K. N. 2010. Changes in Dengue Risk Potential in Hawaii, USA, due to Climate Variability and Change. Climate Research 42:1–11. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kosatsky, T. 2005. The 2003 European Heat Waves. Eurosurveillance 10:148–149. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kulesa, G. 2003. Weather and Aviation: How Does Weather Affect the Safety and Operations of Airports and Aviation, and How Does FAA Work to Manage Weather-related Effects? The Potential Impacts of Climate Change on Transportation, Summary and Discussion Papers, Federal Research Partnership Workshop, October 1–2, 2002. U.S. Department of Transportation Center for Climate Change and Environmental Forecasting. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K. E., D. R. Easterling, K. Hubbard, and K. Redmond. 2009. 2009 update to data originally published in Temporal Variations in Frost-free Season in the United States: 1895–2000. Geophysical Research Letters 31:L03201. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 9. Climate of the Contiguous United States. NOAA Technical Report NESDIS 142-9. National Oceanic and Atmospheric Administration, National

Environmental Satellite, Data, and Information Service. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lambrechts, L., K. P. Paaijmans, T. Fansiri, L. B. Carrington, L. D. Kramer, M. B. Thomas, and T. W. Scott. 2011. Impact of Daily Temperature Fluctuations on Dengue Virus Transmission by Aedes Aegypti. Proceedings of the National Academy of Sciences 108:7460–7465. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lin, B. B. 2011. Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change. BioScience 61:183–193. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Luedeling, E. 2012. Climate Change Impacts on Winter Chill for Temperate Fruit and Nut Production: A Review. Scientia Horticulturae 144:218–229. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Luedeling, E., M. Zhang, and E. H. Girvetz. 2009. Climatic Changes Lead to Declining Winter Chill for Fruit and Nut Trees in California during 1950–2099. PLoS ONE 4:e6166. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Maclellan, N. 2009. Rising Tides—Responding to Climate Change in the Pacific. Social Alternatives 28:8–13. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mader, T. L. 2012. Impact of Environmental Stress on Feedlot Cattle. Western Section, American Society of Animal Science 62:335–339. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Maes, M., F. Meyer, P. Thompson, D. Peeters, and P. Cosyns. 1994. Synchronized Annual Rhythms in Violent Suicide Rate, Ambient Temperature and the Light-dark Span. Acta Psychiatrica Scandinavica 90:391–396. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Markandya, A., B.G. Armstrong, S. Hales, A. Chiabai, P. Criqui, S. Mima, C. Tonne, and P. Wilkinson. 2009. Public Health Benefits of Strategies to Reduce Greenhouse-gas Emissions: Low-carbon Electricity Generation. The Lancet 374:2006–2015. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Martin-Latry, K., M. P. Goumy, P. Latry,

C. Gabinski, B. Bégaud, I. Faure, and H. Verdoux. 2007. Psychotropic Drugs Use and Risk of Heat-related Hospitalisation. European Psychiatry 22:335–338. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mass, C., A. Skalenakis, and M. Warner. 2011. Extreme Precipitation over the West Coast of North America: Is There a Trend? Journal of Hydrometeorology 12:310–318. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McFarlane, A. C., and M. Van Hooff 2009. Impact of Childhood Exposure to a Natural Disaster on Adult Mental Health: 20-year Longitudinal Follow-up Study. The British Journal of Psychiatry 195:142–148. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McMahon, S. M., G. G. Parker, and D. R. Miller. 2010. Evidence for a Recent Increase in Forest Growth. Proceedings of the National Academy of Sciences 107:3611–3615. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Meyer, M. D., A. Amekudzi, and J. P. O'Har. 2010. Transportation Asset Management Systems and Climate Change. Transportation Research Record: Journal of the Transportation Research Board 2160:12–20. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mildrexler, D. J., M. Zhao, and S. W. Running. 2009. Testing a MODIS Global Disturbance Index Across North America. Remote Sensing of Environment 113:2103–2117. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Millar, C. I., and C. W. Swanston. 2012. Ch. 4: Strategies for Adapting to Climate Change. Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector. General Technical Report PNW-GTR-870. U.S. Department of Agriculture. U.S. Forest Service, Pacific Northwest Research Station. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mills, J. N., K. L. Gage, and A. S. Khan. 2010. Potential Influence of Climate Change on Vector-borne and Zoonotic diseases: A Review and Proposed Research Plan. Environmental Health Perspectives 118:1507–1514. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Misselhorn, A., P. Aggarwal, P. Ericksen, P. Gregory, L. Horn-Phathanothai, J. Ingram, and K. Wiebe. 2012. A Vision for Attaining Food Security. Current Opinion in Environmental Sustainability 4:7–17. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Morin, C. W., and A. C. Comrie. 2010. Modeled Response of the West Nile Virus Vector Culex Wuinquefasciatus to Changing Climate using the Dynamic Mosquito Simulation Model. International Journal of Biometeorology 54:517–529. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mudarri, D., and W. J. Fisk. 2007. Public Health and Economic Impact of Dampness and Mold. Indoor Air 17:226–235. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Nakazawa, Y., R. Williams, A. T. Peterson, P. Mead, E. Staples, and K. L. Gage. 2007. Climate Change Effects on Plague and Tularemia in the United States. Vector-Borne and Zoonotic Diseases 7:529–540. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** National Insurance Crime Bureau. 2013. Sandy Vehicles Load Airport Runway. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NIOSH. 1986. Occupational Exposure to Hot Environments: Revised Criteria 1986. Department of Health and Human Services, National Institute for Occupational Safety and Health. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NOAA. 2012: Billion-Dollar Weather/Climate Disasters, Distribution and Change: 2000 to 2010, Summary Statistics. NOAA's National Climatic Data Center. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NPCC. 2009. Climate Risk Information. New York City Panel on Climate Change. New York, NY. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NRC. 2006. Facing Hazards and Disasters: Understanding Human Dimensions. National Research Council, Committee on Disaster Research in the Social Sciences: Future Challenges and Opportunities, Division on Earth and Life Studies. National Academy Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NRC. 2008. Potential Impacts of Climate Change on U.S. Transportation. Special Report 290. Transportation Research Board, National Research Council, Committee on Twenty-First Century Systems Agriculture. The National Academies Press. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** O'Neal, M. R., M. A. Nearing, R. C. Vining, J. Southworth, and R. A. Pfeifer. 2005. Climate Change Impacts on Soil Erosion in Midwest United States with Changes in Crop Management. Catena 61:165–184. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Oerke, E.-C. 2006. Crop Losses to Pests. The Journal of Agricultural Science 144:31–43. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ogden, N. H., L. St-Onge, I. K. Barker, S. Brazeau, M. Bigras-Poulin, D. F. Charron, C. Francis, A. Heagy, L. R. Lindsay, A. Maarouf, P. Michel, F. Milord, C. J. O'Callaghan, L. Trudel, and R. A. Thompson. 2008. Risk Maps for Range Expansion of the Lyme Disease Vector, Ixodes scapularis, in Canada now and with Climate Change. International Journal of Health Geographics 7:24. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ortiz, R., K. D. Sayre, B. Govaerts, R. Gupta, G. V. Subbarao, T. Ban, D. Hodson, J. M. Dixon, J. Iván Ortiz-Monasterio, and M. Reynolds. 2008. Climate Change: Can Wheat Beat the Heat? Agriculture, Ecosystems & Environment 126:46–58. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Page, L. A., S. Hajat, and R. S. Kovats. 2007. Relationship between Daily Suicide Counts and Temperature in England and Wales. The British Journal of Psychiatry 191:106–112. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Patz, J. A., S. J. Vavrus, C. K. Uejio, and S. L. McLellan. 2008. Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S. American Journal of Preventive Medicine 35(5):451–458. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Peel, J. L., R. Haeuber, V. Garcia, A. G. Russell, and L. Neas. 2013. Impact of Nitrogen and Climate Change Interactions on Ambient Air Pollution and Human Health. Biogeochemistry 114:121–134. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Peterson, T. C., P. A. Stott, and S. Herring, 2012. Explaining Extreme Events of 2011 from a Climate Perspective. Bulletin of the American Meteorological Society 93:1041–1067. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Phillips, B. D., D. S. K. Thomas, A.

Fothergill, and L. Blinn-Pike (eds.). 2009. Social Vulnerability to Disasters. First Edition. Boca Raton, FL: CRC Press of the Taylor and Francis Group. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pietrowsky, R., D. Raff, C. McNutt, M. Brewer, T. Johnson, T. Brown, M. Ampleman, C. Baranowski, J. Barsugli, L. D. Brekke, L. Brekki, M. Crowell, D. Easterling, A. Georgakakos, N. Gollehon, J. Goodrich, K. A. Grantz, E. Greene, P. Groisman, R. Heim, C. Luce, S. McKinney, R. Najjar, M. Nearing, D. Nover, R. Olsen, C. Peters-Lidard, L. Poff, K. Rice, B. Rippey, M. Rodgers, A. Rypinski, M. Sale, M. Squires, R. Stahl, E. Z. Stakhiv, and M. Strobel. 2012. Water Resources Sector Technical Input Report in Support of the U.S. Global Change Research Program. National Climate Assessment. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Polvani, L. M., D. W. Waugh, G. J. P. Correa, and S. W. Son. 2011. Stratospheric Ozone Depletion: The Main Driver of Twentieth-century Atmospheric Circulation Changes in the Southern Hemisphere. Journal of Climate 24(3):795–812. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Porter, J. H., M. L. Parry, and T. R. Carter, 1991. The Potential Effects of Climatic Change on Agricultural Insect Pests. Agricultural and Forest Meteorology 57:221–240. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Raffa, K. F., B. H. Aukema, B. J. Bentz, A. L. Carroll, J. A. Hicke, M. G. Turner, and W. H. Romme. 2008. Cross-scale Drivers of Natural Disturbances Prone to Anthropogenic Amplification: The Dynamics of Bark Beetle Eruptions. BioScience 58:501–517. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ramos, M. M., Mohammed, H., Zielinski-Gutierrez, E., Hayden, M. H., Lopez, J. L. R., Fournier, M., & Waterman, S. H. 2008. Epidemic Dengue and Dengue Hemorrhagic Fever at the Texas–Mexico Border: Results of a Household-based Seroepidemiologic Survey, December 2005. The American Journal of Tropical Medicine and Hygiene 78(3):364–369. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rhodes, J., C. Chan, C. Paxson, C. E. Rouse, M. Waters, and E. Fussell. 2010. The Impact of Hurricane Katrina on the Mental and Physical Health of Low-income Parents in New Orleans. American Journal of Orthopsychiatry 80:237–247. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Riget, F., K. Vorkamp, and D. Muir. 2020. Temporal Trends of Contaminants in Arctic char (Salvelinus alpinus) from a Small Lake,

Southwest Greenland during a Warming Climate. Journal of Environmental Monitoring 12:2252–2258. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rizak, S., and S.E. Hrudey. 2008. Drinking-water Safety: Challenges for Community-managed Systems. Journal of Water Health 6:33–42. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rötter, R., and S. C. Van de Geijn. 1999. Climate Change Effects on Plant Growth, Crop Yield and Livestock. Climatic Change 43:651–681. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sathaye, J. A., L. L. Dale, P. H. Larsen, G. A. Fitts, K. Koy, S. M. Lewis, and A. F. P. de Lucena. 2013. Estimating Impacts of Warming Temperatures on California's Electricity System. Global Environmental Change 23:499–511. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schmier, J. K., and K. L. Ebi. 2009. The Impact of Climate Change and Aeroallergens on Children's Health. Allergy and Asthma Proceedings: 229–237. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schrank, D. L., T. J. Lomax, and B. Eisele. 2011. The Urban Mobility Report. Texas Transportation Institute, The Texas A&M University System. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Shea, K. M., R. T. Truckner, R. W. Weber, and D. B. Peden. 2008. Climate Change and Allergic Disease. Journal of Allergy and Clinical Immunology 122:443–453. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sheffield, P. E., and P. J. Landrigan. 2011. Global Climate Change and Children's Health: Threats and Strategies for Prevention. Environmental Health Perspectives 119:291–298. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sheffield, P. E., K. R. Weinberger, K. Ito, T. D. Matte, R. W. Mathers, G. S. Robinson, and P. L. Kinney. 2011b. The Association of Tree Pollen Concentration Peaks and Allergy Medication Sales in New York City: 2003–2008. ISRN Allergy 2011:1–7. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Staudt, A., P. Glick, D. Mizejewski, and

D. Inkley. 2010. Extreme Allergies and Global Warming. National Wildlife Federation and Asthma and Allergy Foundation of America. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stöllberger, C., W. Lutz, and J. Finsterer. 2009. Heat-related Side-effects of Neurological and Non-neurological Medication May Increase Heatwave Fatalities. European Journal of Neurology 16:879–882. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stone, B., J. J. Hess, and H. Frumkin. 2010. Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change than Compact Cities? Environmental Health Perspectives 118:1425–1428. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** The Community Preventive Services Task Force. 2013. The Community Guide: The Guide to Community Preventive Services. Centers for Disease Control and Prevention. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Tomich, T., S. Brodt, F. Ferris, R. Galt, W. Horwath, E. Kebreab, J. Leveau, D. Liptzin, M. Lubell, and P. Merel. 2011. Agroecology: A Review from a Global-change Perspective. Annual Review of Environment and Resources 36:193–222. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** U.S. Census Bureau. 2012a. United States Census 2010. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** U.S. Census Bureau. 2012b. 2010 Census Urban and Rural Classification and Urban Area Criteria. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Van Kleef, E., H. Bambrick, and S. Hales. 2010. The Geographic Distribution of Dengue Fever and the Potential Influence of Global Climate Change. TropIKA.net:1–22. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fule, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, and T. T. Veblen. 2009. Widespread Increase of Tree Mortality Rates in the Western United States. Science 323:521–524. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Vedenov, D. V., S. W. Fuller, B. A. McCarl, W. Attavanich, and Z. Ahmedov. 2011. Effect of Climate Change on Crop Production

Patterns with Implications to Transport Flows and Inland Waterways. University Transportation Center for Mobility, Texas Transportation Institute. The Texas A&M University System. College Station, TX and Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Vose, J. M., D. L. Peterson, and T. Patel-Weynand, Eds. 2012. Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector. General Technical Report PNW-GTR-870. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wall, E., and B. Smit. 2005. Climate Change Adaptation in Light of Sustainable Agriculture. Journal of Sustainable Agriculture 27:113–123. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Walthall, C., P. Backlund, J. Hatfield, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E. A. Ainsworth, C. Amman, C. J. Anderson, I. Bartomeus, L. H. Baumgard, F. Booker, B. Bradley, D. M. Blumenthal, J. Bunce, K. Burkey, S. M. Dabney, J. A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D. A. Grantz, D. Goodrich, S. Hu, R. C. Izaurralde, R. A. C. Jones, S.-H. Kim, A. D. B. Leaky, K. Lewers, T. L. Mader, A. McClung, J. Morgan, D. J. Muth, M. Nearing, D. M. Oosterhuis, D. Ort, C. Parmesan, W. T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W. A. Salas, L. E. Sollenberger, R. Srygley, C. Stöckle, E. S. Takle, D. Timlin, J. W. White, R. Winfree, L. Wright-Morton, and L. H. Ziska. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. U.S. Department of Agriculture and the U.S. Global Change Research Program. Unpublished. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wilbanks, T., S. Fernandez, G. Backus, P. Garcia, K. Jonietz, P. Kirshen, M. Savonis, B. Solecki, and L. Toole. 2012. Climate Change and Infrastructure, Urban Systems, and Vulnerabilities. Technical report to the U.S. Department of Energy in support of the National Climate Assessment. Oak Ridge National Laboratory. U.S Department of Energy, Office of Science. Oak Ridge, TN. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Williams, A. P., and C. Funk. 2011. A Westward Extension of the Warm Pool Leads to a Westward Extension of the Walker Circulation, Drying Eastern Africa. Climate Dynamics 37(11–12):2417–2435. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wischmeier, W. H., and D. D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. U.S. Department of Agriculture. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wolf, J., N. R. R. O'Neill, C. A. Rodgers, M. L. Muilenberg, and L. H. Ziska. 2010. Elevated Atmospheric Carbon Dioxide Concentrations Amplify Alternaria Alternate Sporulation and Total Antigen Production. Environmental Health Perspectives 118:1223–1228. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Xiong, X., E. W. Harville, D. R. Mattison, K. Elkind-Hirsch, G. Pridjian, and P. Buekens. 2008. Exposure to Hurricane Katrina, Post-traumatic Stress Disorder and Birth Outcomes. The American Journal of the Medical Sciences 336:111–115. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Yu, W., K. Mengersen, X. Wang, X. Ye, Y. Guo, X. Pan, and S. Tong. 2011. Daily Average Temperature and Mortality Among the Elderly: A Meta-analysis and Systematic Review of Epidemiological Evidence. International Journal of Biometeorology 56:569–581. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L. H. 2001. Changes in Competitive Ability between a C4 Crop and a C3 Weed with Elevated Carbon Dioxide. Weed Science 49:622–627. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L. H. 2003. Evaluation of the Growth Response of Six Invasive Species to Past, Present and Future Atmospheric Carbon Dioxide. Journal of Experimental Botany 54:395–404. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L. H. 2010. Elevated Carbon Dioxide Alters Chemical Management of Canada Thistle in No-till Soybean. Field Crops Research 119:299–303. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L., K. Knowlton, C. Rodgers, D. Dalan, N. Tierney, M.A. Elder, W. Filley, J. Shropshire, L.B. Ford, C. Hedberg, P. Fleetwood, K.T. Hovanky, T. Kavanaugh, G. Fulford, R.F. Vrtis, J.A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz. 2011. Recent Warming by Latitude Associated with Increased Length of Ragwood Pollen Season in central North America. Proceedings of the National Academy of Sciences 108(10):4248–4251. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dobiesz, N. E., and N. P. Lester. 2009. Changes in mid-summer water temperature and clarity across the Great Lakes between 1968 and 2002. Journal of Great Lakes Research 35:371–384. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Adams, R. M., B. A. McCarl, K. Segerson,

C. Rosenzweig, K. J. Bryant, B. L. Dixon, R. Conner, R. E. Evenson, and D. Ojima. 1999. Ch. 2: The Economic Effects of Climate Change on U.S. Agriculture. In: The Impact of Climate Change on the United States Economy. Cambridge University Press, pgs. 18–54. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Albrecht, G., G. M. Sartore, L. Connor, N. Higginbotham, S. Freeman, B. Kelly, H. Stain, A. Tonna, and G. Pollard. 2007. Solastalgia: The Distress Caused by Environmental Change. Australasian Psychiatry 15:95–98. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Alexandrov, V. A., and G. Hoogenboom. 2000. Vulnerability and adaptation assessments of agricultural crops under climate change in the Southeastern USA. Theoretical and Applied Climatology 67:45–63. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Austin, J. A., and S. M. Colman. 2007. Lake Superior Summer Water Temperatures Are Increasing More Rapidly than Regional Air Temperatures: A Positive Ice-Albedo Feedback. Geophysical Research Letters 34:L06604. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** AWF, AEC, and Entergy. 2010. Building a Resilient Energy Gulf Coast: Executive Report. America's Wetland Foundation, America's Energy Coast, and Entergy. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bai, X., and J. Wang. 2012. Atmospheric Teleconnection Patterns Associated with Severe and Mild Ice Cover on the Great Lakes, 1963–2011. Water Quality Research Journal of Canada 47:421–435. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Berry, L., F. Bloetscher, N. Hernández Hammer, M. Koch-Rose, D. Mitsova-Boneva, J. Restrepo, T. Root, and R. Teegavarapu. 2011. Florida Water Management and Adaptation in the Face of Climate Change. Florida Climate Change Task Force. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bischof, M. M., M. A. Hanson, M. R. Fulton, R. K. Kolka, S. D. Sebestyen, and M. G. Butler. 2013. Invertebrate Community Patterns in Seasonal Ponds in Minnesota, USA: Response to Hydrologic and Environmental Variability. Wetlands 33:245–256. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bloetscher, F., B. Heimlich, and D. E. Meeroff. 2011. Development of an Adaptation Toolbox to Protect Southeast Florida Water Supplies from

Climate Change. Environmental Reviews 19:397–417. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bronte, C. R., M. P. Ebener, D. R. Schreiner, D. S. DeVault, M. M. Petzold, D. A. Jensen, C. Richards, and S. J. Lozano. 2003. Fish Community Change in Lake Superior, 1970–2000. Canadian Journal of Fisheries and Aquatic Sciences 60:1552–1574. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Brook, B. W., N. S. Sodhi, and C. J. A. Bradshaw. 2008. Synergies among Extinction Drivers under Global Change. Trends in Ecology & Evolution 23:453–460. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Burkett, V. 2011. Global Climate Change Implications for Coastal and Offshore Oil and Gas Development. Energy Policy 39:7719–7725. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Burkett, V. R. 2008. Ch. 8: The Northern Gulf of Mexico Coast: Human Development Patterns, Declining Ecosystems, and Escalating Vulnerability to Storms and Sea Level Rise. In: Sudden and Disruptive Climate Change: Exploring the Real Risks and How We Can Avoid Them. Earthscan Publications, pgs. 101–118. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Butry, D. T., E. D. Mercer, J. P. Prestemon, J. M. Pye, and T. P. Holmes. 2001. What Is the Price of Catastrophic Wildfire? Journal of Forestry 99:9–17. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** CAST. 2011. Carbon Sequestration and Greenhouse Gas Fluxes in Agriculture: Challenges and Opportunities. Task Force Report No.142. Council for Agricultural Science and Technology. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Chang, H. H., J. Zhou, and M. Fuentes. 2010. Impact of Climate Change on Ambient Ozone Level and Mortality in Southeastern United States. International Journal of Environmental Research and Public Health 7:2866–2880. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Coastal Louisiana Tribal Communities. 2012. Stories of Change: Coastal Louisiana Tribal Communities' Experiences of a Transforming Environment (Grand Bayou, Grand Caillou/Dulac, Isle de Jean Charles, Pointe-au-Chien). Workshop Report Input into the National Climate Assessment. Pointe-aux-Chenes, Louisiana. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Coker, A. L., S. Hanks, K. S. Eggleston, J. Risser, P. G. Tee, K. J. Chronister, C. L. Troisi, R. Arafat, and L. Franzini. 2006. Social and Mental Health Needs Assessment of Katrina Evacuees. Disaster Management & Response 4:88–94. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Couvillion, B. R., J. A. Barras, G. D. Steyer, W. Sleavin, M. Fischer, H. Beck, N. Trahan, B. Griffin, and D. Heckman. 2011. Land Area Change in Coastal Louisiana from 1932 to 2010: U.S. Geological Survey Scientific Investigations Map 3164. U.S. Geological Survey. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Delfino, R. J., S. Brummel, J. Wu, H. Stern, B. Ostro, M. Lipsett, A. Winer, D. H. Street, L. Zhang, T. Tjoa, and D. L. Gillen. 2009. The Relationship of Respiratory and Cardiovascular Hospital Admissions to the Southern California Wildfires of 2003. Occupational and Environmental Medicine 66:189–197. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** DHS. 2011. Louisiana Highway 1/Port Fourchon Study. U.S. Department of Homeland Security. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ebi, K. L., J. Balbus, P. L. Kinney, E. Lipp, D. Mills, M. S. O'Neill, and M. Wilson. 2008. Ch. 2: Effects of Global Change on Human Health. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems. U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Filler, S. J., J. R. MacArthur, M. Parise, R. Wirtz, M. J. Eliades, A. Dasilva, and R. Steketee. 2006. Locally Acquired Mosquito Transmitted Malaria: A Guide for Investigations in the United States. Morbidity and Mortality Weekly Report, Recommendations and Reports 55:1–9. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Foden, W., G. Mace, J.-C. Vié, A. Angulo, S. Butchart, L. DeVantier, H. Dublin, A. Gutsche, S. Stuart, and E. Turak. 2008. Species Susceptibility to Climate Change Impacts. The 2008 Review of the IUCN Red List of Threatened Species. IUCN. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Friedenberg, N. A., J. A. Powell, and M. P. Ayres. 2007. Synchrony's double Edge: Transient Dynamics and the Allee Effect in Stage Structured Populations. Ecology Letters 10:564–573. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gelfand, I., S. S. Snapp, and G. P. Robertson. 2010. Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the U.S. Midwest. Environmental Science and Technology 44:4006–4011. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidgard, T. C. Richmond, K. Reckhow, K. White, and D. Yates. 2013. Chapter 3: Water Resources. In: Federal Advisory Committee Draft Climate Assessment Report Released for Public Review. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gotham, D., J. R. Angel, and S. C. Pryor. 2013. Ch. 12: Vulnerability of the Electricity and Water Sectors to Climate Change in the Midwest. In: Climate Change in the Midwest: Impacts, Risks, Vulnerability and Adaptation. Indiana University Press, pgs. 192–211. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Grabow, M. L., S. N. Spak, T. Holloway, B. Stone, Jr., A. C. Mednick, and J. A. Patz. 2012. Air Quality and Exercise-related Health Benefits from Reduced Car Rravel in the Midwestern United States. Environmental Health Perspectives 120:68–76. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gramley, M. 2005. Fire in the South: A Report by the Southern Group of State Foresters. Winder, GA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gu, L., P. J. Hanson, W. Mac Post, D. P. Kaiser, B. Yang, R. Nemani, S. G. Pallardy, and T. Meyers. 2008. The 2007 Eastern US Spring Freezes: Increased Cold Damage in a Warming World? BioScience 58:253–262. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hales, S., P. Weinstein, and A. Woodward. 1999. Ciguatera (fish poisoning), El Niño, and Pacific Sea Surface Temperatures. Ecosystem Health 5:20–25. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hatfield, J. L., K. J. Boote, B. A. Kimball, L. H. Ziska, R. C. Izaurralde, D. Ort, A. M. Thomson, and D. Wolfe. 2011. Climate Impacts on Agriculture: Implications for Crop Production. Agronomy Journal 103:351–370. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hatfield, J., K. Boote, P. Fay, L. Hahn, C. Izaurralde, B. A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thompson, and D. Wolfe. 2008.

Ch. 2: Agriculture. The Effects of Climate Change on Agriculture, Land Resources, and Biodiversity in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Department of Agriculture. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hatfield, J. L., R. M. Cruse, and M. D. Tomer. 2013. Convergence of Agricultural Intensification and Climate Change in the Midwestern United States: Implications for Soil and Water Conservation. Marine and Freshwater Research 64(5):423–435. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hellmann, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes. 2008. Five Potential Consequences of Climate Change for Invasive Species. Conservation Biology 22:534–543. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ingram, K., K. Dow, L. Carter, J. Anderson. 2013. Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability. Washington DC Prepared for the National Climate Assessment, Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** IPCC (Intergovernmental Panel on Climate Change). 2007b. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jump, A. S., C. Mátyás, and J. Peñuelas. 2009. The Altitude-for-Latitude Disparity in the Range Retractions of Woody Species. Trends in Ecology & Evolution 24:694–701. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Knutson, T. R., J. L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J. P. Kossin, A. K. Srivastava, and M. Sugi. 2010. Tropical Cyclones and Climate Change. Nature Geoscience 3:157–163. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, C. E. Konrad, II, C. M. Fuhrman, B. D. Keim, M., C. Kruk, A. Billet, H. Needham, M. Schafer, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S. NOAA Technical Report. Washington DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K. E, L. E. Stevens, S. E. Stevens,

L. Sun, E. Janssen, D. Wuebbles, S. D. Hilberg, M. S. Timlin, L. Stoecker, N. E. Westcott, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 3. Climate of the Midwest U.S., NOAA Technical Report NESDIS 142-3. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Leurig, S., and A. Dlugolecki. 2013. Insurance Climate Risk Disclosure Survey: 2012 Findings & Recommendations. Ceres. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Litaker, R. W., M. W. Vandersea, M. A. Faust, S. R. Kibler, A. W. Nau, W. C. Holland, M. Chinain, M. J. Holmes, and P. A. Tester. 2010. Global Distribution of Ciguatera Causing Dinoflagellates in the Genus Gambierdiscus. Toxicon 56:711–730. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Luber, G., and M. McGeehin. 2008: Climate Change and Extreme Heat Events. American Journal of Preventive Medicine 35:429–435. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mackey, S. 2012. Great Lakes Nearshore and Coastal Systems. U.S. National Climate Assessment Midwest Technical Input Report, J. Winkler, J. Andresen, J. Hatfield, D. Bidwell, and D. Brown (eds.), Great Lakes Integrated Sciences and Assessments (GLISA), National Laboratory for Agriculture and the Environment, 14. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mali, S., S. P. Kachur, and P. M. Arguin. 2012. Malaria Surveillance—United States, 2010. Morbidity and Mortality Weekly Report 61:1–17. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** National Agricultural Statistics Service. 2012. Crop Production 2011 Summary. U.S. Department of Agriculture. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NRC (National Research Council). 2011. Frontiers in Understanding Climate Change and Polar Ecosystems Summary of a Workshop. National Research Council: National Academies Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Obeysekera, J., M. Irizarry, J. Park, J. Barnes, and T. Dessalegne. 2011. Climate Change and its Implications for Water Resources Management in South Florida. Stochastic Environmental Research and Risk Assessment 25:495–516. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Osgood, K. E. 2008. Climate Impacts on US Living Marine Resources: National Marine Fisheries Services Concerns, Activities and Needs. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Portier, C. J., T. K. Thigpen, S. R. Carter, C. H. Dilworth, A. E. Grambsch, J. Gohlke, J. Hess, S. N. Howard, G. Luber, J. T. Lutz, T. Maslak, N. Prudent, M. Radtke, J. P. Rosenthal, T. Rowles, P. A. Sandifer, J. Scheraga, P. J. Schramm, D. Strickman, J. M. Trtanj, and P.-Y. Whung. 2010. A Human Health Perspective on Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change. Environmental Health Perspectives and the National Institute of Environmental Health Services, Research. Triangle Park, NC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** PRCCC. 2013. State of Puerto Rico's Climate 2010–2013 Executive Summary. Assessing Puerto Rico's Social-Ecological Vulnerabilities in a Changing Climate. Puerto Rico Climate Change Council. Puerto Rico Coastal Zone Management Program, Department of Natural and Environmental Resources, Office of Ocean and Coastal Resource Management (NOAA-OCRM). San Juan, PR. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** SFWMD. 2009. Climate Change and Water Management in South Florida. Interdepartmental Climate Change Group Report. South Florida Water Management District. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sousounis, P., and J. M. Bisanz (eds.). 2000. Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change: Great Lakes. University of Michigan, Atmospheric, Oceanic and Space Sciences Department. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stanton, E. A., and F. Ackerman. 2007. Florida and Climate Change: The Cost of Inaction. Tufts University, Global Development and Environment Institute, Stockholm Environment Institute-US Center. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** State of Louisiana. 2012. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Draft, January 2012. State of Louisiana. Coastal Protection and Restoration Authority. Baton Rouge, LA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sun, G., S. Arumugam, P. V. Caldwell, P.

A. Conrads, A. P. Covich, J. Cruise, J. Feldt, A. P. Georgakakos, R. T. McNider, S. G. McNulty, D. A. Marion, V. Misra, T. C. Rasmussen, L. Romolo, and A. Terando. 2013. Impacts of Climate Change and Variability on Water Resources in the Southeast USA. In: Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability. Island Press, pgs. 210–236. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Tagaris, E., K. J. Liao, A. J. DeLucia, L. Deck, P. Amar, and A. G. Russell. 2009. Potential Impact of Climate Change on Air Pollution Related Human Health Effects. Environmental Science & Technology 43:4979–4988. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Tebaldi, C., B. H. Strauss, and C. E. Zervas,. 2012. Modelling Sea Level Rise Impacts on Storm Surges along US Coasts. Environmental Research Letters 7:014032. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Tester, P. A., R. L. Feldman, A. W. Nau, S. R. Kibler, and R. Wayne Litaker. 2010. Ciguatera Fish Poisoning and Sea Surface Temperatures in the Caribbean Sea and the West Indies. Toxicon 56:698–710. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Trout, A., G. Baraco, M. Rodriguez, M. Barber, J. Leal, and E. Radke. 2010. Locally Acquired Dengue – Key West, Florida, 2009–2010. Morbidity and Mortality Weekly Report 59:577–581. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Trumpickas, J., B. J. Shuter, and C. K. Minns. 2009. Forecasting Impacts of Climate Change on Great Lakes Surface Water Temperatures. Journal of Great Lakes Research 35:454–463. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Twilley, R. R., E. Barron, H. L. Gholz, M. A. Harwell, R. L. Miller, D. Reed, J. B. Rose, E. Siemann, R. G. Welzel, and R. J. Zimmerman. 2001. Confronting Climate Change in the Gulf Coast Region: Prospects for Sustaining Our Ecological Heritage. Union of Concerned Scientists, Ecological Society of America. Cambridge, MA and Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** U.S. Department of Commerce. 2013. State and Country QuickFacts: Population 2013 Estimate. United States Census Bureau. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** UNEP. 2008. Climate Change in the Caribbean and the Challenge of Adaptation. United Nations Environment Programme. Regional

Office for Latin America and the Caribbean, Panama City, PA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NOAA. 2013b. Billion Dollar Weather/Climate Disasters, List of Events. National Oceanic and Atmospheric Administration. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NPCC. 2010. Climate Change Adaptation in New York City: Building a Risk Management Response: New York City Panel on Climate Change 2009 Report. Vol. 1196. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Tech Memo OAR CPO-1. National Oceanic and Atmospheric Administration. Silver Spring, MD. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Primack, D., C. Imbres, R. B. Primack, A. J. Miller-Rushing, and P. Del Tredici. 2004. Herbarium Specimens Demonstrate Earlier Flowering Times in Response to Warming in Boston. American Journal of Botany 91:1260–1264. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Redman, R. L., C. A. Nenn, D. Eastwood, and M. H. Gorelick. 2007. Pediatric Emergency Department Visits for Diarrheal Illness Increased after Release of Undertreated Sewage. Pediatrics 120:e1472–e1475. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rochlin, I., D. V. Ninivaggi, M. L. Hutchinson, and A. Farajollahi. 2013. Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA: Implications for Public Health Practitioners. PLoS ONE 8:e60874. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sallenger, A. H., K. S. Doran, and P. A. Howd. 2012. Hotspot of Accelerated Sea-level Rise on the Atlantic Coast of North America. Nature Climate Change 2:884–888. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sheffield, P. E., J. L. Carr, P. L. Kinney, and K. Knowlton. 2011. Modeling of Regional Climate Change Effects on Ground-level Ozone and Childhood Asthma. American Journal of Preventive Medicine 41:251–257. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stromayer, K. A. K., and R. J. Warren. 1997. Are Overabundant Deer Herds in the Eastern United States creating Alternative Stable States in Forest Plant Communities? Wildlife Society Bulletin 25:227–234. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wolfe, D. W., J. Comstock, A. Lakso, L. Chase, W. Fry, C. Petzoldt, R. Leichenko, and P. Vancura. 2011. Ch. 7: Agriculture. In: Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State. Blackwell Publishing, pgs. 217–254. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wolfe, D. W., L. Ziska, C. Petzoldt, A. Seaman, L. Chase, and K. Hayhoe. 2008. Projected Change in Climate Thresholds in the Northeastern U.S.: Implications for Crops, Pests, Livestock, and Farmers. Mitigation and Adaptation Strategies for Global Change 13:555–575. Washington, DC, U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L. H., and G. B. Runion. 2007. Future Weed, Pest, and Disease Problems for Plants. In: Agroecosystems in a Changing Climate. CRC Press, pgs. 261–287. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L. H., J. R. Teasdale, and J. A. Bunce. 1999. Future Atmospheric Carbon Dioxide May Increase Tolerance to Glyphosate. Weed Science 47:608–615. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Alaska Department of Commerce and Community and Economic Development. 2012. Relocation Report: Newtok to Mertarvik. Alaska Department of Commerce and Community and Economic Development. Anchorage, AK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Australian Bureau of Meteorology, and CSIRO. 2011. Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. Volume 2: Country Reports. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Barnett, J., and W. N. Adger. 2003. Climate Dangers and Atoll Countries. Climatic Change 61:321–337. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Becker, M., B. Meyssignac, C. Letetrel, W. Llovel, A. Cazenave, and T. Delcroix. 2012. Sea Level Variations at Tropical Pacific Islands Since

1950. Global and Planetary Change 80–81 and 85–98. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bender, S., E. Burke, D. Chahim, L. Eshbach, L. L. Gordon, F. Kaplan, K. McCusker, H. Palevsky, M. Rowell, D. Battisti, J. Barcelos, J. Marlow, and S. Stzern. 2011. Initial Assessment of Lead Agency Candidates to Support Alaska Native Villages Requiring Relocation to Survive Climate Harms. University of Washington Climate Justice Seminar Spring 2011, Three Degrees Project. Seattle, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Benning, T. L., D. LaPointe, C. T. Atkinson, and P. M. Vitousek. 2002. Interactions of Climate Change with Biological Invasions and Land Use in the Hawaiian Islands: Modeling the Fate of Endemic Birds using a Geographic Information System. Proceedings of the National Academy of Sciences 99:14246–14249. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bradley, B. A., D. M. Blumenthal, D. S. Wilcove, and L. H. Ziska. 2010. Predicting Plant Invasions in an Era of Global Change. Trends in Ecology & Evolution 25:310–318. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Brady, M., and J. Taylor. 2011. Agriculture's Contribution to Washington's Economy, IMPACT Center Fact Sheet. Washington State University. Pullman, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bronen, R. 2011. Climate-induced Community Relocations: Creating an Adaptive Governance Framework Based in Human Rights Doctrine. NYU Review Law & Social Change 35:357–408. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Brubaker, M. Y., J. N. Bell, J. E. Berner, and J. A. Warren. 2011. Climate Change Health Assessment: A Novel Approach for Alaska Native Communities. International Journal of Circumpolar Health 70. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Brubaker, M., J. Bell, and A. Rolin. 2009. Climate Change Effects on Traditional Inupiaq Food Cellars. CCH Bulletin No. 1. Alaska Native Tribal Health Consortium, Center for Climate and Health. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Bruno, J. F., E. R. Selig, K. S. Casey, C. A. Page, B. L. Willis, C. D. Harvell, H. Sweatman, and A. M. Melendy. 2007. Thermal Stress and Coral

Cover as Drivers of Coral Disease Outbreaks. PLoS Biology 5:e124. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cao, G., T. W. Giambelluca, D. E. Stevens, and T. A. Schroeder. 2007. Inversion Variability in the Hawaiian Trade Wind Regime. Journal of Climate 20:1145–1160. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Capalbo, S., J. Julian, T. Maness, and E. Kelly. 2010. Ch. 8: Toward Assessing the Economic Impacts of Climate Change on Oregon. In: The Oregon Climate Assessment Report, K. D. Dello, and P. W. Mote, (eds.), Oregon Climate Change Research Institute, College of Oceanic and Atmospheric Sciences. Oregon State University, pgs. 363–396. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cesar, H. S. J., and P. J. H. van Beukering, 2004: Economic Valuation of the Coral Reefs of Hawaiʻi. Pacific Science 58:231–242. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. Magana Rueda, L. Mearns, C. G. Menendez, J. Räisänen, A. Rinke, A. Sarr, and P. Chu, P. S., and H. Chen. 2005. Interannual and Interdecadal Rainfall Variations in the Hawaiian Islands. Journal of Climate 18:4796–4813. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Christensen, K. 2003. Cooperative Drought Contingency Plan—Hualapai Reservation. Hualapai Tribe Department of Natural Resources. Peach Springs, AZ. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Codiga, D., and K. Wager, 2011: Sea-level Rise and Coastal Land Use in Hawaiʻi: A Policy Tool Kit for State and Local Governments. University of Hawaiʻi Sea Grant College Program. Center for Island Climate Adaptation and Policy. Honolulu, HI. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Crozier, L. G., A. P. Hendry, P. W. Lawson, T. P. Quinn, N. J. Mantua, J. Battin, R. G. Shaw, and R. B. Huey. 2008. Potential Responses to Climate Change in Organisms with Complex Life Histories: Evolution and Plasticity in Pacific Salmon. Evolutionary Applications 1:252–270. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Daigle, J. J., and D. Putnam. 2009. The Meaning of a Changed Environment: Initial Assessment of Climate Change Impacts in Maine – Indigenous Peoples. In: Maine's Climate Future: An Initial Assessment. University of Maine, pgs. 37–40. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Diaz-Pulido, G., K. R. N. Anthony, D. I. Kline, S. Dove, and O. Hoegh-Guldberg. 2012. Interactions between Ocean Acidification and Warming on the Mortality and Dissolution of Coralline Algae. Journal of Phycology 48:32–39. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dittmer, K. 2013. Changing Streamflow on Columbia Basin Tribal Lands—Climate Change and Salmon. Climatic Change 120:627–641. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dyson, K., and D. D. Huppert. 2010. Regional Economic Impacts of Razor Clam Beach Closures due to Harmful Algal Blooms (HABs) on the Pacific Coast of Washington. Harmful Algae 9:264–271. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Elsner, M. M., L. Cuo, N. Voisin, J. S. Deems, A. F. Hamlet, J. A. Vano, K. E. B. Mickelson, S. Y. Lee, and D. P. Lettenmaier. 2010. Implications of 21st Century Climate Change for the Hydrology of Washington State. Climatic Change 102:225–260. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** EPA. 2012. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010. U.S. Environmental Protection Agency. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Feely, R. A., C. L. Sabine, J. M. Hernandez-Ayon, D. Ianson, and B. Hales. 2008. Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf. Science, 320, 1490–1492. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Feely, R. A., S. C. Doney, and S. R. Cooley. 2009. Ocean Acidification: Present Conditions and Future Changes in a High-CO2 World. Oceanography 22:36–47. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Feely, R. A., S. R. Alin, J. Newton, C. L. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The Combined Effects of Ocean Acidification, Mixing, and Respiration on pH and Carbonate Saturation in an Urbanized Estuary. Estuarine, Coastal and Shelf Science 88:442–449. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Feely, R. A., T. Klinger, J. A. Newton, and M. Chadsey, (eds.). 2012. Scientific Summary of Ocean Acidification in Washington State Marine

Waters. NOAA OAR Special Report #12-01-016. National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fenner, D., M. Speicher, S. Gulick, G. Aeby, S. Cooper, P. Anderson, B. Carroll, E. DiDonato, G. DiDonato, V. Farmer, J. Gove, P. Houk, E. Lundland, M. Nadon, E. Riolo, M. Sabater, R. Schroeder, E. Smith, C. Tuitele, A. Tagarino, S. Vaitautolu, E. Vaoli, B. Vargas-Angel, and P. Vroom. 2008. Ch. 10: The State of Coral Reef Ecosystems of American Samoa. In: The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Fleming, P., and J. Rufo-Hill. 2012. Seattle Public Utilities and Sea Level Rise, Summary Document. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ganachaud, A. S., A. S. Gupta, J. C. Orr, S. E. Wiffels, K. R. Ridgway, M. A. Hemer, C. Maes, C. R. Steinberg, A. D. Tribollet, B. Qiu, and J. C. Kruger. 2011. Ch. 3: Observed and Expected Changes to the Tropical Pacific Ocean. In: Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community. Noumea, New Caledonia, pgs. 101–188. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Giambelluca, T. W., H. F. Diaz, and M. S. A. Luke. 2008. Secular Temperature Changes in Hawaiʻi. Geophysical Research Letters 35:L12702. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gilman, E. L., J. Ellison, N. C. Duke, and C. Field. 2008. Threats to Mangroves from Climate Change and Adaptation Options: A Review. Aquatic Botany 89:237–250. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Groisman, P. Y., R. W. Knight, T. R. Karl, D. R. Easterling, B. Sun, and J. H. Lawrimore. 2004. Contemporary Changes of the Hydrological Cycle over the Contiguous United States: Trends Derived from In Situ Observations. Journal of Hydrometeorology 5:64–85. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hamlet, A. F., S. Y. Lee, K. E. B. Mickelson, and M. M. Elsner. 2010. Effects of Projected Climate Change on Energy Supply and Demand in the Pacific Northwest and Washington State. Climatic Change 102:103–128. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Henry, R., and W. Jeffery. 2008.

Waterworld: The Heritage Dimensions of Climate Change in the Pacific. Historic Environment 21:12–18. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hickey, B. M., and N. S. Banas. 2008. Why is the Northern End of the California Current System so Productive. Oceanography 21:90–107. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hollowed, A. B., S. R. Hare, and W. S. Wooster. 2001. Pacific Basin Climate Variability and Patterns of Northeast Pacific Marine Fish Production. Progress in Oceanography 49:257–282. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Huntington, H. P., S. Fox, F. Berkes, and I. Krupnik. 2005. The Changing Arctic – Indigenous Perspectives. In: Arctic Climate Impact Assessment. Cambridge University Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** IPCC (Intergovernmental Panel on Climate Change). 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jokiel, P. L., and E. K. Brown. 2004. Global Warming, Regional Trends and Inshore Environmental Conditions Influence Coral Bleaching in Hawaii. Global Change Biology 10:1627–1641. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Juroszek, P., and A. Von Tiedemann. 2013. Plant pathogens, Insect Pests and Weeds in a Changing Global Climate: A Review of Approaches, Challenges, Research Gaps, Key Studies and Concepts. The Journal of Agricultural Science 151:163–188. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Keith, P. 2003. Biology and Ecology of Amphidromous Gobiidae of the Indo-Pacific and the Caribbean Regions. Journal of Fish Biology 63:831–847. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** King County Department of Natural Resources and Parks. 2008. Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise. King County (WA) Department of Natural Resources and Parks, Wastewater Treatment Division, Seattle, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kline, D. I., L. Teneva, K. Schneider, T. Miard, A. Chai, M. Marker, K. Headley, B. Opdyke, M. Nash, M. Valetich, J. K. Caves, B. D. Russell, S. D. Connell, B. J. Kirkwood, P. Brewer, E. Peltzer, J. Silverman, K. Caldeira, R. B. Dunbar, J. R. Koseff, S. G. Monismith, B. G. Mitchell, S. Dove, and O. Hoegh-Guldberg. 2012. A Short-term In Situ CO2 Enrichment Experiment on Heron Island (GBR). Scientific Reports 2. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Krushelnycky, P. D., L. L. Loope, T. W. Giambelluca, F. Starr, K. Starr, D. R. Drake, A. D. Taylor, and R. H. Robichaux. 2013. Climate Associated Population Declines Reverse Recovery and Threaten Future of an Iconic High Elevation Plant. Global Change Biology 19:911–922. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 6. Climate of the Northwest U.S. NOAA Technical Report NESDIS 142-6. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lenihan, J. M., D. Bachelet, R. P. Neilson, and R. Drapek. 2008. Simulated Response of Conterminous United States Ecosystems to Climate Change at Eifferent Levels of Fire Suppression, CO2 Emission Rate, and Growth Response to CO2. Global and Planetary Change 64:16–25. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lewis, N. 2012. Islands in a Sea of Change: Climate Change, Health and Human Security in Small Island States. In: National Security and Human Health Implications of Climate Change. Springer, pgs. 13–24. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Littell, J. S., D. L. Peterson, C. I. Millar, and K. A. O'Halloran. 2012. US National Forests Adapt to Climate Change through Science–Management Partnerships. Climatic Change 110:269–296. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** MacArthur, J., P. Mote, J. Ideker, M. Figliozzi, and M. Lee. 2012. Climate Change Impact Assessment for Surface Transportation in the Pacific Northwest and Alaska. WA-RD 772.1. OTREC-RR-12-01. Washington State Department of Transportation, Oregon Transportation Research and Education Consortium. Olympia, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate Change Impacts on Streamflow Extremes and Summertime Stream Temperature and their Possible Consequences for Freshwater Salmon Habitat in Washington State. Climatic Change 102:187–223. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McKenney, D. W., J. H. Pedlar, R. B. Rood, and D. Price. 2011. Revisiting Projected Shifts in the Climate Envelopes of North American Trees Using Updated General Circulation Models. Global Change Biology 17:2720–2730. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McKenzie, D., D. L. Peterson, and J. J. Littell. 2008. Ch. 15: Global Warming and Stress Complexes in Forests of Western North America. In: Developments in Environmental Sciences. Elsevier, Ltd., pgs. 319–337. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Merrifield, M. A. 2011. A Shift in Western Tropical Pacific Sea Level Trends during the 1990s. Journal of Climate 24:4126–4138. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Moore, S. K., N. J. Mantua, B. M. Hickey, and V. L. Trainer. 2009. Recent Rrends in Paralytic Shellfish Toxins in Puget Sound, Relationships to Climate, and Capacity for Prediction of Toxic Events. Harmful Algae 8:463–477. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mote, P. W. 2006. Climate-driven Variability and Trends in Mountain Snowpack in Western North America. Journal of Climate 19:6209–6220. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mote, P. W., and E. P. Salathé. 2010. Future Climate in the Pacific Northwest. Climatic Change 102:29–50. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mote, P. W., D. Gavin, and A. Huyer. 2010. Climate Change in Oregon's Land and Marine Environments. Oregon Climate Assessment Report. Corvallis, OR. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mueter, F. J., N. A. Bond, J. N. Ianelli, and A. B. Hollowed. 2011. Expected Declines in Recruitment of Walleye Pollock (Theragra chalcogramma) in the Eastern Bering Sea under Future Climate Change. ICES Journal of Marine Science 68:1284–1296. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mundy, P. R., and D. F. Evenson. 2011. Environmental Controls of Phenology of High-Latitude Chinook Salmon Populations of the Yukon River, North America, with Application to Fishery Management. ICES Journal of Marine Science 68:1155–1164. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Neal, E. G., E. Hood, and K. Smikrud. 2010. Contribution of Glacier Runoff to Freshwater Discharge into the Gulf of Alaska. Geophysical Research Letters 37:1–5. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Nerem, R. S., D. P. Chambers, C. Choe, and G. T. Mitchum. 2010. Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions. Marine Geodesy 33:435–446. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NOAA. 2010. NOAA Ocean and Great Lakes Acidification Research Plan, NOAA Special Report. Oceanic and Atmospheric Administration – Ocean Acidification Steering Committee. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Oerlemans, J. 2005. Extracting a Climate Signal from 169 Glacier Records. Science 308:675–677. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Oki, D. S. 2004. Trends in Streamflow Characteristics at Long-Term Gaging Stations, Hawaii. U.S. Geological Survey Scientific Report 2004-5080. U.S. Geological Survey. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Osterkamp, T. E., and V. E. Romanovsky. 1999. Evidence for Warming and Thawing of Discontinuous Permafrost in Alaska. Permafrost and Periglacial Processes 10:17–37. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Overeem, I., R. S. Anderson, C. W. Wobus, G. D. Clow, F. E. Urban, and N. Matell. 2011. Sea Ice Loss Enhances Wave Action at the Arctic Coast. Geophysical Research Letters 38:L17503. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. Annual Review of Ecology, Evolution, and Systematics 37:637–669. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pearcy, W. G. 2002. Marine Nekton Off

Oregon and the 1997–98 El Niño. Progress in Oceanography 54:399–403. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pelto, M. 2011. Utility of Late Summer Transient Snowline Migration Rate on Taku Glacier, Alaska. The Cryosphere Discussions 5:1365–1382. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pratchett, M. S., P. L. Munday, N. A. J. Graham, M. Kronen, S. Pinca, K. Friedman, T. D. Brewer, J. D. Bell, S. K. Wilson, J. E. Cinner, J. P. Kinch, R. J. Lawton, A. J. Williams, L. Chapman, F. Magron, and A. Webb. 2011. Ch. 9: Vulnerability of Coastal Fisheries in the Tropical Pacific to Climate Change: Summary for Pacific Island Countries and Territories. In: Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community, pgs. 367–370. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Radić, V., and R. Hock. 2011. Regionally Differentiated Contribution of Mountain Glaciers and Ice Caps to Future Sea-Level Rise. Nature Geoscience 4:91–94. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Reclamation. 2011. Reclamation Managing Water in the West. SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water 2011. U.S. Department of the Interior, U.S. Bureau of Reclamation. Denver, CO. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Regehr, E. V., N. J. Lunn, S. C. Amstrup, and I. Stirling. 2007. Effects of Earlier Sea Ice Breakup on Survival and Population Size of Polar Bears in Western Hudson Bay. The Journal of Wildlife Management 71:2673–2683. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rehfeldt, G. E., N. L. Crookston, C. Sáenz-Romero, and E. M. Campbell. 2012. North American Vegetation Model for Land-Use Planning in a Changing Climate: A Solution to Large Classification Problems. Ecological Applications 22:119–141. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rieman, B. E., and D. J. Isaak. 2010. Climate Change, Aquatic Ecosystems, and Fishes in the Rocky Mountain West: Implications and Alternatives for Management. Gen. Tech. Rep. RMRS-GTR-250. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ries, J. B., A. L. Cohen, and D. C.

McCorkle. 2009. Marine Calcifiers Exhibit Mixed Responses to CO2-induced Ocean Acidification. Geology 37:1131–1134. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Roach, J., B. Griffith, D. Verbyla, and J. Jones. 2011. Mechanisms Influencing Changes in Lake Area in Alaskan Boreal Forest. Global Change Biology 17:2567–2583. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rode, K. D., S. C. Amstrup, and E. V. Regehr. 2010. Reduced Body Size and Cub Recruitment in Polar Bears Associated with Sea Ice Decline. Ecological Applications 20:768–782. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rogers, B. M., R. P. Neilson, R. Drapek, J. M. Lenihan, J. R. Wells, D. Bachelet, and B. E. Law. 2011. Impacts of Climate Change on Fire Regimes and Carbon Stocks of the US Pacific Northwest. Journal of Geophysical Research 116:G03037. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Romanovsky, V. E., S. S. Marchenko, R. Daanen, D. O. Sergeev, and D. A. Walker. 2008. Soil Climate and Frost Heave along the Permafrost/Ecological North American Arctic Transect. Proceedings of the Ninth International Conference on Permafrost, Institute of Northern Engineering. University of Alaska Fairbanks. Achorage, AK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rover, J., L. Ji, B. K. Wylie, and L. L. Tieszen. 2012. Establishing Water Body Areal Extent Trends in Interior Alaska from Multi-Temporal Landsat Data. Remote Sensing Letters 3:595–604. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ruiz, G. M., P. W. Fofonoff, J. T. Carlton, M. J. Wonham, and A. H. Hines. 2000. Invasion of Coastal Marine Communities in North America: Apparent Patterns, Processes, and Biases. Annual Review of Ecology and Systematics 31:481–531. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sambrotto, R. N., C. Mordy, S. I. Zeeman, P. J. Stabeno, and S. A. Macklin. 2008. Physical Forcing and Nutrient Conditions Associated with Patterns of Chl A and Phytoplankton Productivity in the Southeastern Bering Sea during Summer. Deep Sea Research Part II: Topical Studies in Oceanography 55:1745–1760. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schliebe, S., K. D. Rode, J. S. Gleason, J. Wilder, K. Proffitt, T. J. Evans, and S. Miller. 2008. Effects of Sea Ice Extent and Food Availability on

Spatial and Temporal Distribution of Polar Bears during the Fall Open-Water Period in the Southern Beaufort Sea. Polar Biology 31:999–1010. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schroth, A. W., J. Crusius, F. Chever, B. C. Bostick, and O. J. Rouxel. 2011. Glacial Influence on the Geochemistry of Riverine Iron Fluxes to the Gulf of Alaska and Effects of Deglaciation. Geophysical Research Letters 38:1–6. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Screen, J. A., and I. Simmonds. 2010. The Central Role of Diminishing Sea Ice in Recent Arctic Temperature Amplification. Nature 464:1334–1337. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sigler, M. F., M. Renner, S. L. Danielson, L. B. Eisner, R. R. Lauth, K. J. Kuletz, E. A. Longerwell, and G. L. Hunt. 2011. Fluxes, Fins, and Feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a Time of Climate Change. Oceanography 24:250–265. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Simpson, D. P. 2011. City of Olympia: Engineered Response to Sea Level Rise. Technical Report prepared for the City of Olympia Public Works Department, Planning & Engineering. Coast & Harbor Engineering. Edmonds, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Smith, L. C., and S. R. Stephenson. 2013. New Trans-Arctic Shipping Routes Navigable by Mid Century. Proceedings of the National Academy of Sciences 110:E1191–E1195. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Solecki, W., and C. Rosenzweig (eds.). 2012. U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues, Technical Input Report Series, U.S. National Climate Assessment. U.S. Global Change Research Program. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stammer, D., A. Cazenave, R. M. Ponte, and M. Tamisiea. 2013. Causes for Contemporary Regional Sea Level Changes. Annual Review of Marine Science 5:21–46. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Steinacher, M., F. Joos, T. L. Frölicher, G.-K. Plattner, and S. C. Doney. 2009. Imminent Ocean Acidification in the Arctic Projected with the NCAR Global Coupled Carbon Cycle-Climate Model. Biogeosciences 6:515–533. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stewart, B. C., K. E. Kunkel, L. E. Stevens, L. Sun, and J. E. Walsh. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 7. Climate of Alaska. NOAA Technical Report NESDIS 142-7. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes toward Earlier Streamflow Timing across Western North America. Journal of Climate 18:1136–1155. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stirling, I., M. J. Lunn, and J. Iacozza. 1999. Long-term Trends in the Population Ecology of Polar Bears in Western Hudson Bay in Relation to Climate Change. Arctic 52:294–306. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stöckle, C. O., R. L. Nelson, S. Higgins, J. Brunner, G. Grove, R. Boydston, M. Whiting, and C. Kruger. 2010. Assessment of Climate Change Impact on Eastern Washington Agriculture. Climatic Change 102:77–102. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Storlazzi, C. D., E. Elias, M. E. Field, and M. K. Presto. 2011. Numerical Modeling of the Impact of Sea-level Rise on Fringing Coral Reef Hydrodynamics and Sediment Transport. Coral Reefs 30:83–96. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Strauss, B. H., R. Ziemlinski, J. L. Weiss, and J. T. Overpeck. 2012. Tidally Adjusted Estimates of Topographic Vulnerability to Sea Level Rise and Flooding for the Contiguous United States. Environmental Research Letters 7:014033. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stroeve, J. C., M. C. Serreze, M. M. Holland, J. E. Kay, J. Malanik, and A. P. Barrett. 2012. The Arctic's Rapidly Shrinking Sea Ice Cover: A Research Synthesis. Climatic Change 110:1005–1027. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stroeve, J., M. M. Holland, W. Meier, T. Scambos, and M. Serreze. 2007. Arctic Sea Ice Decline: Faster than Forecast. Geophysical Research Letters 34:L09501. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sussman, M., B. L. Willis, S. Victor, and D. G. Bourne. 2008. Coral Pathogens Identified for White Syndrome (WS) Epizootics in the Indo-Pacific. PLoS ONE 3:e2393. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Tillmann, P., and D. Siemann. 2011. Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region. A Compilation of Scientific Literature. Phase 1 Draft Final Report. National Wildlife Federation-Pacific Region, U.S. Fish and Wildlife Service Region 1 Science Applications Program. Seattle, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Timm, O., and H. F. Diaz. 2009. Synoptic-Statistical Approach to Regional Downscaling of IPCC Twenty-first-century Climate Projections: Seasonal Rainfall over the Hawaiian Islands. Journal of Climate 22:4261–4280. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** UAF 2013. Scenarios Network for Alaska & Arctic Planning. University of Alaska Fairbanks. Anchorage, AK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Vavrus, S., J. E. Walsh, W. L. Chapman, and D. Portis. 2006. The Behavior of Extreme Cold Air Outbreaks under Greenhouse Warming. International Journal of Climatology 26:1133–1147. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Villarini, G., J. A. Smith, M. L. Baeck, and W. F. Krajewski. 2011. Examining Flood Frequency Distributions in the Midwest. U.S. Journal of the American Water Resources Association 47(3), 447–463. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Webb, M. D., and K. W. F. Howard. 2011. Modeling the Transient Response of Saline Intrusion to Rising Sea-levels. Ground Water 49:560–569. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Weller, G. 2005. Summary and Synthesis of the ACIA. In: Arctic Climate Impact Assessment. Cambridge University Press, pp. 989–1020. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wendler, G., and M. Shulski. 2009. A Century of Climate Change for Fairbanks, Alaska. Arctic 62:295–300. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wenger, S. J., D. J. Isaak, C. H. Luce, H. M. Neville, K. D. Fausch, J. B. Dunham, D. C. Dauwalter, M. K. Young, M. M. Elsner, B. E. Rieman, A. F. Hamlet, and J. E. Williams. 2011. Flow Regime, Temperature, and Biotic Interactions Drive

Differential Declines of Trout Species under Climate Change. Proceedings of the National Academy of Sciences 108:14175–14180. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das, and S. R. Shrestha. 2011. Climate Change and Growth Scenarios for California Wildfire. Climatic Change 109:445–463. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. Science 313:940–943. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** White, D. M., S. C. Gerlach, P. Loring, A. C. Tidwell, and M. C. Chambers. 2007. Food and Water Security in a Changing Arctic Climate. Environmental Research Letters 2:045018. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Williams, A. P., C. D. Allen, C. I. Millar, T. W. Swetnam, J. Michaelsen, C. J. Still, and S. W. Leavitt. 2010. Forest Responses to Increasing Aridity and Warmth in the Southwestern United States. Proceedings of the National Academy of Sciences 107:21289–21294. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Woodhouse, C. A., D. M. Meko, G. M. MacDonald, D. W. Stahle, and E. R. Cook. 2010. A 1,200-year Perspective of 21st Century Drought in Southwestern North America. Proceedings of the National Academy of Sciences 107:21283–21288. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Yamamoto-Kawai, M., F. A. McLaughlin, E. C. Carmack, S. Nishino, and K. Shimada. 2009. Aragonite Undersaturation in the Arctic Ocean: Effects of Ocean Acidification and Sea Ice Melt. Science 326:1098–1100. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Yin, J., M. E. Schlesinger, and R. J. Stouffer. 2009. Model Projections of Rapid Sea-level Rise on the Northeast Coast of the United States. Nature Geoscience 2:262–266. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. A. Elder, W. Filley, J. Shropshire, L. B. Ford, C. Hedberg, P. Fleetwood, K. T. Hovanky, T. Kavanaugh, G. Fulford, R. F. Vrtis, J. A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz. 2011. Recent Warming by Latitude Associated with Increased Length of Ragweed Pollen Season in Central North America. Proceedings of the National Academy of Sciences 108:4248–4251. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Allen, C. D., and D. D. Breshears, 1998. Drought-induced Shift of a Forest-Woodland Ecotone: Rapid Landscape Response to Climate Variation. Proceedings of the National Academy of Sciences 95:14839–14842. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Altstatt, J. M., R. F. Ambrose, J. M. Engle, P. L. Haaker, K. D. Lafferty, and P. T. Raimondi, 1996. Recent Declines of Black Abalone Haliotis cracherodii on the Mainland Coast of Central California. Marine Ecology Progress Series 142:185–192. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** AMAP. 2011. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme, Oslo, Norway. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D.R. Cayan, and M. D. Dettinger. 2008. Human-induced Changes in the Hydrology of the Western United States. Science 319:1080–1083. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Basagic, H. J., and A. G. Fountain. 2011. Quantifying 20th Century Glacier Change in the Sierra Nevada, California. Arctic, Antarctic, and Alpine Research 43:317–330. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Beck, P. S. A., G. P. Juday, C. Alix, V. A. Barber, S. E. Winslow, E. E. Sousa, P. Heiser, J. D. Herriges, and S. J. Goetz. 2011. Changes in Forest Productivity across Alaska Consistent with Biome Shift. Ecology Letters 14:373–379. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Brainard, R. E., C. Birkeland, C. M. Eakin, P. McElhany, M. W. Miller, M. Patterson, and G. A. Piniak. 2011. Status Review Report of 82 Candidate Coral Species Petitioned under the U.S. Endangered Species Act. NOAA Technical Memorandum NMFS-PIFSC-27. U.S. Department of Commerce. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Burke, L., L. Reytar, M. Spalding, and A. Perry. 2011. Reefs at Risk Revisited. World Resources Institute. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Burkett, V., and M. Davidson. 2012.

Coastal Impacts, Adaptation and Vulnerabilities: A Technical Input to the 2013 National Climate Assessment. Island Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** California King Tides Initiative. 2012. California King Tides Initiative. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Carpenter, K. E., M. Abrar, G. Aeby, R. B. Aronson, S. Banks, A. Bruckner, A. Chiriboga, J. Cortés, J. C. Delbeek, L. DeVantier, G. J. Edgar, A. J. Edwards, D. Fenner, H. M. Guzmán, B. W. Hoeksema, G. Hodgson, O. Johan, W. Y. Licuanan, S. R. Livingstone, E. R. Lovell, J. A. Moore, D. O. Obura, D. Ochavillo, B. A. Polidoro, W. F. Precht, M. C. Quibilan, C. Reboton, Z. T. Richards, A. D. Rogers, J. Sanciangco, A. Sheppard, C. Sheppard, J. Smith, S. Stuart, E. Turak, J. E. Veron, C. Wallace, E. Weil, and E. Wood. 2008. One-third of Reef-building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. Science 321:560–563. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Carrier, S. D., G. L. Bruland, L. J. Cox, and C. A. Lepczyk. 2012. The Perceptions of Coastal Resource Managers in Hawai'i: The Current Ssituation and Outlook for the Future. Ocean & Coastal Management 69:291–298. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** CCSP. 2009. Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid- Atlantic Region. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Chapin, F. S., III, P. A. Matson, and P. M. Vitousek (eds.). 2011. Principles of Terrestrial Ecosystem Ecology. 2nd edition. Springer Science+Business Media, LLC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cheung, W. W. L., J. Dunne, J. L. Sarmiento, and D. Pauly. 2011. Integrating Ecophysiology and Plankton Dynamics into Projected Maximum Fisheries Catch Potential under Climate Change in the Northeast Atlantic. ICES Journal of Marine Science 68:1008–1018. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cheung, W. W. L., V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, and D. Pauly. 2009. Projecting Global Marine Biodiversity Impacts under Climate Change Scenarios. Fish and Fisheries 10:235–251. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Cooley, S. R., and S. C. Doney. 2009.

Anticipating Ocean Acidification's Economic Consequences for Commercial Fisheries. Environmental Research Letters 4:8. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Das, T., H. G. Hidalgo, D. W. Pierce, T. P. Barnett, M. D., Dettinger, D. R. Cayan, C. Bonfils, G. Bala, and A. Mirin. 2009. Structure and Detectability of Trends in Hydrological Measures over the Western United States. Journal of Hydrometeorology 10:871–892. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dawson, T. P., S. T. Jackson, J. I. House, I. C. Prentice, and G. M. Mace. 2011. Beyond Predictions: Biodiversity Conservation in a Changing Climate. Science 332:53–58. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** DeGaetano, A. T. 2009. Time-dependent Changes in Extreme Precipitation Return-period Amounts in the Continental United States. Journal of Applied Meteorology and Climatology 48:2086–2099. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dial, R. J., E. E. Berg, K. Timm, A. McMahon, and J. Geck. 2007. Changes in the Alpine Forest-Tundra Ecotone Commensurate with Recent Warming in Southcentral Alaska: Evidence from Orthophotos and Field Plots. Journal of Geophysical Research-Biogeosciences 112. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dijkstra, F. A., S. A. Prior, G. B. Runion, H. A. Torbert, H. Tian, C. Lu, and R. T. Venterea. 2012. Effects of Elevated Carbon Dioxide and Increased Temperature on Methane and Nitrous Oxide Fluxes: Evidence from Field Experiments. Frontiers in Ecology and the Environment 10:520–527. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas. 2009. Ocean Acidification: The Other CO_2 Problem. Annual Review of Marine Science 1:169–192. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Doney, S. C., W. M. Balch, V. J. Fabry, and R. A. Feely. 2009. Ocean Acidification: A Critical Emerging Problem for the Ocean Sciences. Oceanography 22:16–25. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Dudgeon, S. R., R. B. Aronson, J. F. Bruno, and W. F. Precht. 2010. Phase Shifts and Stable States on Coral Reefs. Marine Ecology Progress Series 413:201–216. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** EPA. 2010. Climate Change Vulnerability Assessments: A Review of Water Utility Practices. EPA 800-R-10-001. U.S. Environmental Protection Agency, Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Feder, M. E. 2010. Physiology and Global Climate Change. Annual Review of Physiology 72:123–125. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Feng, S., and Q. Hu. 2007. Changes in Winter Snowfall/Precipitation Ratio in the Contiguous United States. Journal of Geophysical Research: Atmospheres 112:D15109. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ferguson, D. B., C. Alvord, M. Crimmins, M. Hiza Redsteer, M. Hayes, C. McNutt, R. Pulwarty, and M. Svoboda. 2011. Drought Preparedness for Tribes in the Four Corners Region. Report from April 2010 Workshop. Climate Assessment for the Southwest. The Climate Assessment for the Southwest (CLIMAS), The Institute of the Environment, The University of Arizona. Tucson, AZ. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** First Stewards. 2012. First Stewards: Coastal Peoples Address Climate Change. National Museum of the American Indian, Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Freeman, C., and M. A. Fox. 2005. Status and Trends in the Education of American Indians and Alaska Natives. NCES 2005–108. National Center for Education Statistics, U.S. Department of Education, Institute of Education Sciences. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Frieler, K., M. Meinshausen, A. Golly, M. Mengel, K. Lebek, S. D. Donner, and O. Hoegh-Guldberg. 2013. Limiting Global Warming to 2°C Is Unlikely to Save Most Coral Reefs. Nature Climate Change 3:165–170. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gan, T. Y., R. G. Barry, M. Gizaw, A. Gobena, and R. Balaji. 2013. Changes in North American Snowpacks for 1979–2007 Detected from the Snow Water Equivalent Data of SMMR and SSM/I Passive Microwave and Related Climatic Factors. Journal of Geophysical Research: Atmospheres 118:7682–7697. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gao, Y., J. A. Vano, C. Zhu, and D. P. Lettenmaier. 2011. Evaluating Climate Change over the Colorado River Basin Using Regional Climate

Models. Journal of Geophysical Research: Atmospheres 116:D13104. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gautam, M. R., K. Chief, and W. J. Smith, Jr. 2013. Climate Change in Arid Lands and Native American Socioeconomic Vulnerability: The Case of the Pyramid Lake Paiute Tribe. Climatic Change 120:585–599. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Godsey, S. E., J. W. Kirchner, and D. W. Clow. 2009. Concentration–Discharge Relationships Reflect Chemostatic Characteristics of US Catchments. Hydrological Processes 23:1844–1864. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Grah, O., and J. Beaulieu. 2013. The Effect of Climate Change on Glacier Ablation and Baseflow Support in the Nooksack River Basin and Implications on Pacific Salmonid Species Protection and Recovery. Climatic Change 120:657–670. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Groisman, P. Y., R. W. Knight, and T. R. Karl. 2012. Changes in Intense Precipitation over the Central United States. Journal of Hydrometeorology 13:47–66. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Gutowski, W. J., G. C. Hegerl, G. J. Holland, T. R. Knutson, L.O. Mearns, R. J. Stouffer, P. J. Webster, M. F. Wehner, and F. W. Zwiers. 2008. Ch. 3: Causes of Observed Changes in Extremes and Projections of Future Changes. Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and US Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hirsch, R. M., and K. R. Ryberg. 2012. Has the Magnitude of Floods across the USA Changed with Global CO2 Levels? Hydrological Sciences Journal 57:1–9. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hodgkins, G. A., and R. W. Dudley. 2006a. Changes in the Timing of Winter–Spring Streamflows in Eastern North America, 1913–2002. Geophysical Research Letters 33:L06402. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hodgkins, G. A., and R. W. Dudley. 2006b. Changes in Late-winter Snowpack Depth, Water Equivalent, and Density in Maine, 1926–2004. Hydrological Processes. 20:741–751. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hodgkins, G. A., I. C. James, and T. G. Huntington. 2002. Historical Changes in Lake Ice-out Dates as Indicators of Climate Change in New England, 1850–2000. International Journal of Climatology 22:1819–1827. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hoegh-Guldberg, O., and J. F. Bruno. 2010. The Impact of Climate Change on the World's Marine Ecosystems. Science 328:1523–1528. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hoegh-Guldberg, O., P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi, and M. E. Hatziolos. 2007. Coral Reefs under Rapid Climate Change and Ocean Acidification. Science 318:1737–1742. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2012. Ch. 5: Evolving Weather and Climate Conditions of the Southwest United States. Assessment of Climate Change in the Southwest United States: A Technical Report Prepared for the U.S. National Climate Assessment. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hönisch, B., A. Ridgwell, D. N. Schmidt, E. Thomas, S. J. Gibbs, A. Sluijs, R. Zeebe, L. Kump, R. C. Martindale, S. E. Greene, W. Kiessling, J. Ries, J. C. Zachos, D. L. Royer, S. Barker, T. M. M. Jr., R. Moyer, C. Pelejero, P. Ziveri, G. L. Foster, and B. Williams. 2012. The Geological Record of Ocean Acidification. Science 335:1058–1063. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Howarth, R. W., D. P. Swaney, E. W. Boyer, R. Marino, N. Jaworski, and C. Goodale. 2006. The Influence of Climate on Average Nitrogen Export from Large Watersheds in the Northeastern United States. Biogeochemistry 79:163–186. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Howarth, R., D. Swaney, G. Billen, J. Garnier, B. Hong, C. Humborg, P. Johnes, C.-M. Mörth, and R. Marino. 2012. Nitrogen Fluxes from the Landscape Are Controlled by Net Anthropogenic Nitrogen Inputs and by Climate. Frontiers in Ecology and the Environment 10. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hughes, T. P., N. A. J. Graham, J. B. C. Jackson, P. J. Mumby, and R. S. Steneck. 2010. Rising to the Challenge of Sustaining Coral Reef

Resilience. Trends in Ecology & Evolution 25:633–642. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Irish, J. L., A. E. Frey, J. D. Rosati, F. Olivera, L. M. Dunkin, J. M. Kaihatu, C. M. Ferreira, and B. L. Edge. 2010. Potential Implications of Global Warming and Barrier Island Degradation on Future Hurricane Inundation, Property Damages, and Population Impacted. Ocean & Coastal Management 53:645–657. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Janssens, I. A., W. Dieleman, S. Luyssaert, J. A. Subke, M. Reichstein, R. Ceulemans, P. Ciais, A. J. Dolman, J. Grace, G. Matteucci, D. Papale, S. L. Piao, E. D. Schulze, J. Tang, and B. E. Law. 2010. Reduction of Forest Soil Respiration in Response to Nitrogen Deposition. Nature Geoscience 3:315–322. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Jones, T., and W. Cresswell. 2010. The Phenology Mismatch Hypothesis: Are Declines of Migrant Birds Linked to Uneven Global Climate Change? Journal of Animal Ecology 79:98–108. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Justić, D., N. N. Rabalais, and R. E. Turner. 2005. Coupling between Climate Variability and Coastal Eutrophication: Evidence and Outlook for the Northern Gulf of Mexico. Journal of Sea Research 54:25–35. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Karl, T. R., and R. W. Knight. 1998. Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States. Bulletin of the American Meteorological Society 79:231–241. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kennedy, J. J., P. W. Thorne, T. C. Peterson, R. A. Reudy, P. A. Stott, D. E. Parker, S. A. Good, H. A. Titchner, and K. M. Willett. 2010. How Do We Know the World has Warmed? [In State of the Climate in 2009]. Bulletin of the American Meteorological Society 91:S26–27. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kharin, V. V., F. W. Zwiers, X. Zhang, and M. Wehner. 2013. Changes in Temperature and Precipitation Extremes in the CMIP5 Ensemble. Climatic Change 119:345–357. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Knorr, M., S. D. Frey, and P. S. Curtis.

2005. Nitrogen Additions and Litter Decomposition: A Meta-Analysis. Ecology 86:3252–3257. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kroeker, K. J., R. L. Kordas, R. Crim, I. E. Hendriks, L. Ramajo, G. S. Singh, C. M. Duarte, and J.-P. Gattuso. 2013. Impacts of Ocean Acidification on Marine Organisms: Quantifying Sensitivities and Interaction with Warming. Global Change Biology 19:1884–1896. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kruse, J. A. 1991. Alaska Inupiat Subsistence and Wage Employment Patterns: Understanding Individual Choice. Human Organization 50:317–326. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Whyte, K. P. 2013. Justice Forward: Tribes, Climate Adaptation and Responsibility. Climatic Change 120, 517–530. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Laidler, G. J., J. D. Ford, W. A. Gough, T. Ikummaq, A. S. Gagnon, S. Kowal, K. Qrunnut, and C. Irngaut. 2009. Travelling and Hunting in a Changing Arctic: Assessing Inuit Vulnerability to Sea Ece Change in Igloolik, Nunavut. Climatic Change 94:363–397. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Ian, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, III, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G. L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. M. Welker, K. S. Winker, and K. Yoshikawa. 2005. Evidence and Implications of Recent Climate Change in Northern Alaska and Other Arctic Regions. Climatic Change 72:251–298. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lawler, J. J., S. L. Shafer, B. A. Bancroft, and A. R. Blaustein. 2010. Projected Climate Impacts for the Amphibians of the Western Hemisphere. Conservation Biology 24:38–50. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lloyd, A. H., and C. L. Fastie. 2003. Recent Changes in Treeline Forest Distribution and Structure in Interior Alaska. Ecoscience 10:176–185. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Luce, C. H., and Z. A. Holden. 2009. Declining Annual Streamflow Distributions in the Pacific Northwest United States, 1948–2006. Geophysical Research Letters 36. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Lynn, K., J. Daigle, J. Hoffman, F. Lake, N. Michelle, D. Ranco, C. Viles, G. Voggesser, and P. Williams. 2013. The Impacts of Climate Change on Tribal Traditional Foods. Climatic Change 120:545–556. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Maldonado, J. K., C. Shearer, R. Bronen, K. Peterson, and H. Lazrus. 2013. The Impact of Climate Change on Tribal Communities in the US: Displacement, Relocation, and Human Rights. Climatic Change 120:601–614. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McCabe, G. J., and D. M. Wolock. 2011. Independent Effects of Temperature and Precipitation on Modeled Runoff in the Conterminous United States. Water Resources Research 47:W11522. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McClintock, S. E. 2009. Ch. 17: Coastal and Riverine Erosion Challenges: Alaskan Villages' Sustainability. In: Climate Change and Arctic Sustainable Development: Scientific, Social, Cultural and Educational Challenges. UNESCO. 120. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McIsaac, G. F., M. B. David, G. Z. Gertner, and D. A. Goolsby. 2002. Relating Net Nitrogen Input in the Mississippi River Basin to Nitrate Flux in the Lower Mississippi River: A Comparison of Approaches. Journal of Environmental Quality 31:1610–1622. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** McNutt, D. 2008. Native Peoples: The "Miners Canary" on Climate Change, 16 pgs., Northwest Indian Applied Research Institute, Evergreen State College. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Merideth, R., D. Liverman, R. Bales, and M. Patterson. 1998. Climate Variability and Change in the Southwest: Impacts, Information Needs, and Issues for Policymaking. Final Report. Southwest Regional Climate Change Symposium and Workshop, Udall Center for Studies in Public Policy, University of Arizona. Tucson, AZ. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Millar, C. I., R. D. Westfall, D. L. Delany, J. C. King, and L. J. Graumlich. 2004. Response of Subalpine Conifers in the Sierra Nevada, California, USA, to 20th-Century Warming and Decadal Climate Variability. Arctic, Antarctic, and Alpine Research 36:181–200. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being. Health Synthesis. Island press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Miller-Rushing, A. J., T. L. Lloyd-Evans, R. B. Primack, and P. Satzinger. 2008. Bird Migration Times, Climate Change, and Changing Population Sizes. Global Change Biology 1959–1972. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Mishra, V., and D. P. Lettenmaier. 2011. Climatic Trends in Major US Urban Areas, 1950–2009. Geophysical Research Letters 38:L16401. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Moore, K. A., and J. C. Jarvis. 2008. Environmental Factors Affecting Recent Summertime Eelgrass Diebacks in the Lower Chesapeake Bay: Implications for Long-term Persistence. Journal of Coastal Research Special Issue 55:135–147. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Moore, K. A., E. C. Shields, D. B. Parrish, and R. J. Orth. 2012. Eelgrass Survival in Two Contrasting Systems: Role of Turbidity and Summer Water Temperatures. Marine Ecology Progress Series 448:247–258. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Moser, S. C. 2009. Good Morning America! The Explosive Awakening of the US to Adaptation. California Energy Commission, NOAA-Coastal Services Center. Sacramento, CA and Charleston, SC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Multihazard Mitigation Council. 2005. Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities. Volume 2 – Study Documentation. National Institute of Building Sciences. Washington, DC. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NASA Earth Observatory. 2012. Visualizing the 2012 Sea Ice Minimum. NASA Earth Observatory, EOS Project Science Office, NASA Goddard Space Flight Center. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Navajo Nation Department of Water Resources. 2011. Draft Water Resource Development Strategy for the Navajo Nation. Navajo Nation

Department of Water Resources, Fort Defiance, AZ. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Nearing, M. A., V. Jetten, C. Baffaut, O. Cerdan, A. Couturier, M. Hernandez, Y. Le Bissonnais, M. H. Nichols, J. P. Nunes, C. S. Renschler, V. Souche're, and K. van Oost. 2005. Modeling Response of Soil Erosion and Runoff to Changes in Precipitation and Cover. Catena 61:131–154. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Neumann, J., D. Hudgens, J. Herter, and J. Martinich. 2010. The Economics of Adaptation along Developed Coastlines. Wiley Interdisciplinary Reviews. Climate Change 2:89–98. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Martinich, J., J. Neumann, L. Ludwig, and L. Jantarasami. 2013. Risks of Sea Level Rise to Disadvantaged Communities in the United States. Mitigation and Adaptation Strategies for Global Change 18(2):169–185.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Nicholls, R. J., and A. Cazenave. 2010. Sea-level Rise and its Impact on Coastal Zones. Science 328:1517–1520. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Nickels, S., C. Furgal, M. Buell, and H. Moquin. 2005. Unikkaaqatigiit: Putting the Human Face on Climate Change: Perspectives from Inuit in Canada, 129 pgs., Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization, Ottawa. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NMFS. 2012. Endangered and Threatened Wildlife and Plants: Proposed Listing Determinations for 82 Reef-Building Coral Species. Proposed Reclassification of Acropora palmata and Acropora cervicornis from Threatened to Endangered. Federal Register 77:773220–773262. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Norris, T., P. L. Vines, and E. M. Hoeffel. 2012. The American Indian and Alaska Native Population: 2010. U.S. Census Bureau. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** NRC. 2010. Advancing the Science of Climate Change. America's Climate Choices: Panel on Advancing the Science of Climate Change. National Research Council. The National Academies Press. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Papiez, C. 2009. Climate Change Implications for the Quileute and Hoh Tribes of Washington: A Multidisciplinary Approach to Assessing Climatic Disruptions to Coastal Indigenous Communities. Master's Thesis, Environmental Studies. The Evergreen State College. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Parkinson, A. J. 2010. Sustainable Development, Climate Change and Human Health in the Arctic. International Journal of Circumpolar Health 69:99–105. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Parkinson, A. J., and B. Evengård. 2009. Climate Change, its Impact on Human Health in the Arctic and the Public Health Response to Threats of Emerging Infectious Diseases. Global Health Action 2. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pierce, D. W., and D. R. Cayan. 2013. The Uneven Response of Different Snow Measures to Human-induced Climate Warming. Journal of Climate 26:4148–4167. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Poulter, B., R. L. Feldman, M. M. Brinson, B. P. Horton, M. K. Orbach, S. H. Pearsall, E. Reyes, S. R. Riggs, and J. C. Whitehead. 2009. Sea-level Rise Research and Dialogue in North Carolina: Creating Windows for Policy Change. Ocean & Coastal Management 52:147–153. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pungowiyi, C. 2002. Special Report on Climate Impacts in the Arctic. Native Peoples-Native Homelands Climate Change Workshop: Final Report: Circles of Wisdom. NASA Goddard Space Flight Center 11–12. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pungowiyi, C. 2009. Siberian Yup'ik Elder, personal communication. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Quileute Newsletter. 2011. Key Committee Approves Cantwell Bill to Move Quileute Tribe out of Tsunami Zone. The Talking Raven: A Quileute Newsletter 5:16. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Redsteer, M. H. 2011. Increasing Vulnerability to Drought and Climate Change on the Navajo Nation, Southwestern United States. Current Conditions & Accounts of Changes during the Last 100 Years. U.S. Geological Survey. 0928. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Redsteer, M. H., K. B. Kelley, H. Francis, and D. Block. 2011. Disaster Risk Assessment Case Study: Recent Drought on the Navajo Nation, Southwestern United States. Contributing Paper for the Global Assessment Report on Disaster Risk Reduction. United Nations Office for Disaster Risk Reduction and U.S. Geological Survey. Reston, VA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Riley, R., P. Blanchard, R. Peppler, T. M. B. Bennett, and D. WilD.Cat. 2012. Oklahoma Inter-Tribal Meeting on Climate Variability and Change: Meeting Summary Report. Norman, OK. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rose, K. A. 2010. Tribal Climate Change Adaptation Options: A Review of the Scientific Literature. U.S. Environmental Protection Agency Region 10. Seattle, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Rotzoll, K., and C. H. Fletcher. 2013. Assessment of Groundwater Inundation as a Consequence of Sea-level Rise. Nature Climate Change 3:477–481. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sabine, C. L., R. A. Feely, N. Gruber, R. M. Key, K. Lee, J. L. Bullister, R. Wanninkhof, C. S. Wong, D. W. R. Wallace, B. Tilbrook, F. J. Millero, T.-H. Peng, A. Kozyr, T. Ono, and A. F. Rios. 2004. The Oceanic Sink for Anthropogenic CO2. Science 305:367–371. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sabo, J. L., T. Sinha, L. C. Bowling, G. H. W. Schoups, W. W. Wallender, M. E. Campana, K. A. Cherkauer, P. L. Fuller, W. L. Graf, J. W. Hopmans, J. S. Kominoski, C. Taylor, S. W. Trimble, R. H. Webb, and E. E. Wohl. 2010. Reclaiming Freshwater Sustainability in the Cadillac Desert. Proceedings of the National Academy of Sciences 107:21263–21269. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Sobota, D. J., J. A. Harrison, and R. A. Dahlgren. 2009. Influences of Climate, Hydrology, and Land Use on Input and Export of Nitrogen in California Watersheds. Biogeochemistry 94:43–62. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Staudt, A., A. K. Leidner, J. Howard, K. A. Brauman, J. S. Dukes, L. J. Hansen, C. Paukert, J. Sabo, and L. A. Solórzano. 2013. The Added Complications of Climate Change: Understanding and Managing Biodiversity and Ecosystems. Frontiers in Ecology and the Environment 11:494–501. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stralberg, D., D. Jongsomjit, C. A. Howell, M. A. Snyder, J. D. Alexander, J. A. Wiens, and T. L. Root. 2009. Re-shuffling of Species with Climate Disruption: A No-Analog Future for California birds? PLoS ONE 4:e6825. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stumpf, R. P., T. T. Wynne, D. B. Baker, and G. L. Fahnenstiel. 2012. Interannual Variability of Cyanobacterial Blooms in Lake Erie. PLoS ONE 7:e42444. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Suarez, F., D. Binkley, M. W. Kaye, and R. Stottlemyer, 1999. Expansion of Forest Stands into Tundra in the Noatak National Preserve, Northwest Alaska. Ecoscience 6:465–470. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Swanson, D. L., and J. S. Palmer. 2009. Spring Migration Phenology of Birds in the Northern Prairie Region Is Correlated with Local Climate Change. Journal of Field Ornithology 80:351–363. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Swinomish Indian Tribal Community. 2010. Swinomish Climate Change Initiative Climate Adaptation Action Plan. Swinomish Indian Tribal Community Office of Planning and Community Development. La Conner, WA. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** TEP. 2011. Tribal Profiles. Alaska – Athabascan Region. Institute for Tribal Environmental Professionals. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Todd, B. D., D. E. Scott, J. H. K. Pechmann, and J. W. Gibbons. 2011. Climate Change Correlates with Rapid Delays and Advancements in Reproductive Timing in an Amphibian Community. Proceedings of the Royal Society B: Biological Sciences 2191–2197. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Trainor, S. F., F. S. Chapin, III, A. D. McGuire, M. Calef, N. Fresco, M. Kwart, P. Duffy, A. L. Lovecraft, T. S. Rupp, L. O. DeWilde, O. Huntington, and D. C. Natcher. 2009. Vulnerability and Adaptation to Climate-related Fire Impacts in Rural and Urban Interior Alaska. Polar Research 28:100–118. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Trenberth, K. E., J. T. Overpeck, and S.

Solomon. 2004. Exploring Drought and its Implications for the Future. Eos, Transactions, American Geophysical Union 85:27. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Tribollet, A., C. Godinot, M. Atkinson, and C. Langdon. 2009. Effects of Elevated pCO2 on Dissolution of Coral Carbonates by Microbial Euendoliths. Global Biogeochemical Cycles 23:GB3008. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** U.S. Commission on Civil Rights. 2003. A Quiet Crisis: Federal Funding and Unmet Needs in Indian Country. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Van Buskirk, J., R. S. Mulvihill, and R. C. Leberman. 2008. Variable Shifts in Spring and Autumn Migration Phenology in North American Songbirds Associated with Climate Change. Global Change Biology 15:760–771. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Villarini, G., and J. A. Smith. 2010. Flood Peak Distributions for the Eastern United States. Water Resources Research 46:W06504. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Villarini, G., F. Serinaldi, J. A. Smith, and W. F. Krajewski. 2009. On the Stationarity of Annual Flood Peaks in the Continental United States during the 20th Century. Water Resources Research 45:W08417. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Voggesser, G., K. Lynn, J. Daigle, F. K. Lake, and D. Ranco. 2013. Cultural Impacts to Tribes from Climate Change Influences on Forests. Climatic Change 120:615–626. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Vose, R. S., S. Applequist, M. J. Menne, C. N. Williams, Jr., and P. Thorne. 2012. An Intercomparison of Temperature Trends in the US Historical Climatology Network and Recent Atmospheric Reanalyses. Geophysical Research Letters 39:6. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Walker, R. 2012. Haida Gwaii Quake Brings Home the Importance of Quileute Relocation Legislation. Indian Country Today Media Network.com. November 6, 2012. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wang, M., and J. E. Overland. 2012. A

Sea Ice Free Summer Arctic within 30 Years: An Update from CMIP5 Models. Geophysical Research Letters 39, L18501. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Whitehead, P., A. Wade, and D. Butterfield. 2009. Potential Impacts of Climate Change on Water Quality in Six UK Rivers. Hydrological Research 40:113–122. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wiebe, K. L., and H. Gerstmar. 2010. Influence of Spring Temperatures and Individual Traits on Reproductive Timing and Success in a Migratory Woodpecker. The Auk 127:917–925. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wilmking, M., G. P. Juday, V. A. Barber, and H. S. J. Zald. 2004. Recent Climate Warming Forces Contrasting Growth Responses of White Spruce at Treeline in Alaska through Temperature Thresholds. Global Change Biology 10:1724–1736. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wisshak, M., C. H. L. Schönberg, A. Form, and A. Freiwald. 2012. Ocean Acidification Accelerates Reef Bioerosion. PLoS ONE 7:e45124. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Melillo, J. M., S. Butler, J. Johnson, J. Mohan, P. Steudler, H. Lux, E. Burrows, F. Bowles, R. Smith, L. Scott, C. Vario, T. Hill, A. Burton, Y. M. Zhou, and J. Tang. 2011. Soil Warming, Carbon-Nitrogen Interactions, and Forest Carbon Budgets. Proceedings of the National Academy of Sciences 108:9508–9512. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Najjar, G.-K. Plattner, K. B. Rodgers, C. L. Sabine, J. L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic Ocean Acidification over the Twenty-First Century and its Impact on Calcifying Organisms. Nature 437:681–686. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pan, Z., M. Segal, R. W. Arritt, and E. S. Takle. 2004. On the Potential Change in Solar Radiation over the US due to Increases of Atmospheric Greenhouse Gases. Renewable Energy 29:1923–1928. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Peñuelas, J., T. Rutishauser, and I.

Filella. 2009. Phenology Feedbacks on Climate Change. Science 324:887–888. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Qian, T., A. Dai, and K. E. Trenberth. 2007. Hydroclimatic Trends in the Mississippi River Basin from 1948 to 2004. Journal of Climate 20:4599–4614. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Schimel, D. S., J. I. House, K. A. Hibbard, P. Bousquet, P. Ciais, P. Peylin, B. H. Braswell, M. J. Apps, D. Baker, A. Bondeau, J. Canadell, G. Churkina, W. Cramer, A. S. Denning, C. B. Field, P. Friedlingstein, C. Goodale, M. Heimann, R. A. Houghton, J. M. Melillo, B. Moore, III, D. Murdiyarso, I. Noble, S. W. Pacala, I. C. Prentice, M. R. Raupach, P. J. Rayner, R. J. Scholes, W. L. Steffen, and C. Wirth. 2001. Recent Patterns and Mechanisms of Carbon Exchange by Terrestrial Ecosystems. Nature 414:169–172. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wu, Z., P. Dijkstra, G. W. P. Koch, J., and B. A. Hungate. 2011. Responses of Terrestrial Ecosystems to Temperature and Precipitation Change: A Meta-analysis of Experimental Manipulation. Global Change Biology 17:927–942. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Hansson, L. A., A. Nicolle, W. Granéli, P. Hallgren, E. Kritz-berg, A. Persson, J. Björk, P. A. Nilsson, and C. Brönmark. 2012. Food-chain Length Alters Community Responses to Global Change in Aquatic Systems. Nature Climate Change 3:228–233. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Kampa, M., and E. Castanas. 2008. Human Health Effects of Air Pollution. Environmental Pollution 151:362–637. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Pinkerton, K.E., W.N. Rom, M. Akpinar-Elci, J.R. Balmes, H. Bayram, O. Brandli, J.W. Hollingsworth, P.L. Kinney, H.G. Margolis, W.J. Martin, E.N. Sasser, K.R. Smith, and T.K. Takaro. 2012. An Official American Thoracic Society Workshop Report: Climate Change and Human Health. Proceedings of the American Thoracic Society 9:3–8, doi: 10.1513/pats.201201-015ST. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Romanovsky, V. E., S. L. Smith, H. H. Christiansen, N. I. Shiklomanov, D. S. Drozdov, N. G. Oberman, A. L. Kholodov, and S. S. Marchenko. 2012. [The Arctic] Permafrost [in State of the Climate in 2011]. Bulletin of the American Meteorological Society 93:S137-S138. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Weeks, D., P. Malone, and L. Welling,

2011: Climate Change Scenario Planning: A Tool for Managing Parks into Uncertain Futures. Park Science 28, 26–33. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Stroeve, J. C., V. Kattsov, A. Barrett, M. Serreze, T. Pavlova, M. Holland, and W. N. Meier. 2012. Trends in Arctic Sea Ice Extent from CMIP5, CMIP3 and Observations. Geophysical Research Letters 39:L16502. Washington DC: U.S. Global Change Research Program.

GCRP. 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment **citing** Wang, M., and J. E. Overland. 2009. A Sea Ice Free Summer Arctic within 30 years? Geophysical Research Letters. 36:L07502. Washington DC: U.S. Global Change Research Program.

GCRP (U.S. Global Change Research Program) et al. 2014. Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment, [J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds.]. U.S. Global Change Research Program, pgs. 220–256.

Gertler, A. W., J. A. Gillies, and W. R. Pierson. 2000. An Assessment of the Mobile Source Contribution to PM10 and PM2.5 in the United States. Water, Air, & Soil Pollution 123(1–4):203–214. doi: 10.1023/A:1005263220659.

Geyer, R. 2008. Parametric Assessment of Climate Change Impacts of Automotive Material Substitution. *Environmental Science & Technology* 42(18):6973–6979.

GFEI (Global Fuel Economy Initiative). 2014. Fuel Economy State of the World 2014: The World is Shifting into Gear on Fuel Economy. London, UK.

Gibson, T. 2000. Life Cycle Assessment of Advanced Materials for Automotive Applications. *Society of Automotive Engineers, Inc.* 109(6):1932–1941.

Gleick, Peter. 2014. Water, Drought, Climate Change, and Conflict in Syria. Weather, Climate, and Society 6:331–340.

Goldenson, N., S. J. Doherty, C. M. Bitz, M. M. Holland, B. Light, and A. J. Conley. 2012. Arctic Climate Response to Forcing from Light-absorbing Particles in Snow and Sea Ice in CESM. A*tmospheric Chemistry and Physics* 12(17):7903–7920.

Goldstein, B. D. 1988. Benzene Toxicity State of the Art Reviews. *Occupational Medicine* 3(3):541–554.

Graham, J. D., N. D. Beaulieu, D. Sussman, M. Sadowitz, and Y-C. Li. 1999. Who Lives Near Coke Plants and Oil Refineries? An Exploration of the Environmental Inequity Hypothesis. *Risk Analysis* 19(2):171–186.

Grimm, N. B., F. S. Chapin III, B. Bierwagen, P. Gonzalez, P. M. Groffman, Y. Luo, F. Melton, K. Nadelhoffer, A. Pairis, P. A. Raymond, J. Schimel, and C. E. Williamson. 2013. The Impacts of Climate Change on Ecosystem Structure and Function. *Frontiers in Ecology and the Environment* 11(9):474–482.

Grinsted, A.J., C. Moore, and S. Jevrejeva. 2010. Reconstructing Sea Level from Paleo and Projected Temperatures 200 to 2100 AD. Climate Dynamics 34(4):461–472. doi: 10.1007/s00382-008-0507-2.

Available at: http://www.glaciology.net/Home/PDFs/Announcements/gslprojection. (Accessed: August 11, 2011) **citing** Hansen, J.E. 2007. Scientific Reticence and Sea Level Rise. Environmental Research Letters 2: 024002. doi:10.1088/1748-9326/2/2/024002.

Grinsted, A., J. C. Moore, and S. Jevrejeva. 2013. Projected Atlantic Hurricane Surge Threat from Rising Temperatures. Proceedings of the National Academy of Sciences 110(14):5369–5373.

Groisman, P. Y., R. W. Knight, and O. G. Zolina. 2013. Recent Trends in Regional and Global Intense Precipitation Patterns. Pages 25–55 in R. A. Pielke (ed.), Climate Vulnerability. Academic Press.

Gronewold, A. D., and C. A. Stow. 2014. Water Loss from the Great Lakes. *Science Magazine* 343(6175):1084–1085.

Guinotte, J. M., and V. J. Fabry. 2008. Ocean Acidification and its Potential Effects on Marine Ecosystems. *Annals of the New York Academy of Sciences* 1134(1):320–342.

Haddeland, I., J. Heinke, H. Biemans, S. Eisner, M. Flörke, N. Hanasaki, M. Konzmann, F. Ludwig, Y. Masaki, J. Schewe, T. Stacke, Z. D. Tessler, Y. Wada, and D. Wisseri. 2014. Global Water Resources Affected by Human Interventions and Climate Change. *Proceedings of the National Academy of Sciences* 111(9):3251–3256.

Hajat, S., S. Vardoulaakis, C. Heaviside, and B. Eggen. 2014. Climate Change Effects on Human Health: Projections of Temperature-related Mortality for the UK during the 2020s, 2050s and 2080s. *Journal of Epidemiology and Community Health* 68(7):641–648.

Hakamada, M., T. Furuta, Y. Chino, Y. Chen, H. Kusuda, and M. Mabuchi. 2007. Life Cycle Inventory Study on Magnesium Alloy Substitution in Vehicles. *Energy* 32(8):1352–1360. doi: 10.1016/j.energy.2006.10.020.

Hall, M. H., and D. B. Fagre. 2003. Modeled Climate-induced Glacier Change in Glacier National Park, 1850–2100. *BioScience* 53(2):131–140.

Hambly, D., J. Audrey, B. Mills, and C. Fletcher. 2013. Projected Implications of Climate Change for Road Safety in Greater Vancouver, Canada. *Climatic Change* 116(3-4):613–629.

Hamburg, S. 2013. Measuring Fugitive Methane Emissions. Environmental Defense Fund. *Available at*: http://blogs.edf.org/energyexchange/2013/01/04/measuring-fugitive-methane-emissions/. (Accessed: June 2014).

Hammer, M. S., T. K. Swinburn, and R. L. Neitzel. 2013. Environmental Noise Pollution in the United States: Developing an Effective Public Health Response. National Institute of Environmental Health Sciences. *Available at*: http://ehp.niehs.nih.gov/wp-content/uploads/122/2/ehp.1307272.pdf. (Accessed: June 5, 2014).

Handmer, J., Y. Honda, Z.W. Kundzewicz, N. Arnell, G. Benito, J. Hatfield, I.F. Mohamed, P. Peduzzi, S. Wu, B. Sherstyukov, K. Takahashi, and Z. Yan. 2012. Changes in Impacts of Climate Extremes: Human Systems and Ecosystems. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK, and New York, NY.

Hannah, L., P. R. Roehrdanz, M. Ikegami, A. V. Shepard, M. R. Shaw, F. Tabor, L. ZAhi, P. A. Marquet, and R. J. Hijmans. 2013. Climate Change, Wine, and Conservation. *Proceedings of the National Academy of Sciences* 110(17):6907–6912.

Hansen, J. E., and M. Sato. 2012. Paleoclimate Implications for Human-Made Climate Change. In: Climate Change. Inferences from Paleoclimate and Regional Aspects. Springer Vienna, pgs. 21–47.

Hansen, J., Kharecha, P., Sato, M., Masson-Delmotte, V., Ackerman, F., Beerling, D. J., Zachos, J. C. 2013. Assessing Dangerous Climate Change: Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature. PLoS ONE 8(12):e81648. doi:10.1371/journal.pone.0081648.

Hanson, S., R. Nicholls, N. Ranger, S. Hallegatte, J. U. Corfee-Morlot, C. Herweijer, and J. Chateau. 2011. A Global Ranking of Port Cities with High Exposure to Climate Extremes. *Climatic Change* 104(1):89–111.

Hart, J. E., E. B. Rimm, K. M. Rexrode, and F. Laden. 2013. Changes in Traffic Exposure and the Risk of Incident Myocardial Infarction and All-cause Mortality. *Epidemiology* 24(5):734–742.

Harville, E. W., X. Xiong, and P. Buekens. 2009. Hurricane Katrina and Perinatal Health. *Birth* 36(4):325–331.

Hauptmann, M., J. H. Lubin, P. A. Steward, R. B. Hayes, and A. Blair. 2003. Mortality from Lymphohematopoietic Malignancies among Workers in Formaldehyde Industries. Journal of the National Cancer Institute 95(21):1615–1623. doi: 10.1093/jnci/djg083. *Available at*: http://jnci.oxfordjournals.org/content/95/21/1615.full.pdf+html. (Accessed: February 16, 2015).

Hauptmann, M., J. H. Lubin, P. A. Stewart, R. B. Hayes, and A. Blair. 2004. Mortality from Solid Cancers among Workers in Formaldehyde Industries. *American Journal of Epidemiology* 159(12):1117–1130.

Hauptmann, M., P. A. Stewart, J. H. Lubin, L. E. Beane Freeman, R. W. Hornung, R. F. Herrick, R. N. Hoover, J. F. Fraumeni, A. Blair, and R. B. Hayes. 2009. Mortality from Lymphohematopoietic Malignancies and Brain Cancer among Embalmers Exposed to Formaldehyde. *Journal of the National Cancer Institute* 101(24):1696–1708.

He, Z., M. Xu, Y. Deng, S. Kang, L. Kellogg, L. Wu, J. D. Van Nostrand, S. E. Hobbie, P. B. Reich, and J. Zhou. 2010. Metagenomic Analysis Reveals a Marked Divergence in the Structure of Belowground Microbial Communities at Elevated CO_2. *Ecology Letters* 13(5):564–575.

Heath, G. A., P. O'Donoughue, D. J. Arent, and M. Bazilian. 2014. Harmonization of Initial Estimates of Shale Gas Life Cycle Greenhouse Gas Emissions for Electric Power Generation. Proceedings of the National Academy of Sciences of the United States, Early Edition 1309334111:1–10.

Heath, J., E. Ayres, M. Possell, R. D. Bardgett, H. I. J. Black, H. Grant, P. Ineson, and G. Kerstiens. 2005. Rising Atmospheric CO2 Reduces Sequestration of Root-derived Soil Carbon. *Science* 309(5741):1711–1713.

HEI (Health Effects Institute). 2010. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure and Health Effects: Special Report 17. Boston, MA, Health Effects Institute: HEI Panel on the Health Effects of Traffic-Related Air Pollution, 386 pgs.

Heinrich, J., and H.-E. Wichmann. 2004. Traffic Telated Pollutants in Europe and their Effect on Allergic Disease. *Current Opinion in Allergy and Clinical Immunolog*y 4(5):341–348.

HHS (U.S. Department of Health and Human Services). 2003. National Healthcare Disparities Report. U.S. Department of Health and Human Service. Rockville, MD, Agency for Healthcare Research and Quality.

Hodgkins, G. A., R. W. Dudley, and T. G. Huntington. 2005. Changes in the Number and Timing of Days of Ice-affected Flow on Northern New England Rivers, 1930–2000. *Climatic Change* 71(3):319–340.

Holt, D.E. 2001. Auxiliary Power Units. Service Technology Magazine.

Hondula, D. M., M. Georgescu, and R. C. Balling Jr. 2014. Challenges Associated with Projecting Urbanization-induced Heat-related Mortality. *Science of the Total Environment* 490:538–544.

Hooidonk, R., J. A. Maynard, D. Manzello, and S. Planes. 2014. Opposite Latitudinal Gradients in Projected Pcean Acidification and Bleaching Impacts on Coral Reefs. *Global Change Biology* 30(1):103–112.

Howarth, R. W. 2011. Should Fracking Stop? *Nature* 4(7):7.

Howell, A. J., and J. M. Timberlake. 2014. Racial and Ethnic Trends in the Suburbanization of Poverty in U.S. Metropolitan Areas, 1980–2010. *Journal of Urban Affairs* 36(1):79–98.

Hu, A., G. A. Meehl, W. Han, and J. Yin. 2009. Transient Response of the MOC and Climate to Potential Melting of the Greenland Ice Sheet in the 21st Century. *Geophysical Research Letters* 36(10).

Hu, Q., A. Weiss, S. Feng, and P. S. Baenziger. 2005. Earlier Winter Wheat Heading Dates and Warmer Spring in the U.S. Great Plains. *Agricultural and Forest Meteorology* 135:284–290.

Hu, S., S. Fruin, K. Kozawa, S. Mara, S. E. Paulson, and A. M. Winer. 2009. A Wide Area of Air Pollutant Impact Downwind of a Freeway during Pre-sunrise Hours. *Atmospheric Environmen*t 43(16):2541–2549.

Hu, S., S. E. Paulson, S. Fruin, K. Kozawa, S. Mara, and A. M. Winer. 2012. Observation of Elevated Air Pollutant Concentrations in a Residential Neighborhood of Los Angeles California Using a Mobile Platform. A*tmospheric Environment* 51:311–319.

Huong, H., and A. Pathirana. 2013. Urbanization and Climate Change Impacts on Future Urban Flooding in Can Tho City, Vietnam. *Hydrology and Earth System Sciences* 17(1):379–394.

IARC (International Agency for Research on Cancer). 1982. Benzene. *IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans* 29:93–148.

IARC. 1987. Benzene. *Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans* 29(Supplement 7):120–122.

IARC. 1995. Dry Cleaning, Some Chlorinated Solvents and Other Industrial Chemicals 63:337–338.

IARC. 1999. Re-evaluation of Some Organic Chemicals, Hydrazine, and Hydrogen Peroxide. *Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans* 71:109–225.

IARC. 2006. Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. *Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans* 88:37–326.

IARC. 2012. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans, Chemical Agents and Related Occupations. World Health Organization 100F.

IARC. 2013. Diesel and Gasoline Engine Exhausts and Some Nitroarenes. IARC Monographs Volume 105. *Available at*: http://monographs.iarc.fr/ENG/Monographs/vol105/index.php. (Accessed: June 17, 2015).

ICCATF (Interagency Climate Change Adaptation Task Force). 2011. National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate. U.S. Department of Commerce. Executive Office of the President of the U.S. Washington, DC, National Oceanic and Atmospheric Administration.

ICCT (International Council on Clean Transportation). 2014. Where We Work: China. *Available at*: http://www.theicct.org/china. (Accessed: June 11, 2014).

IEC (Industrial Economics, Inc.). 2011. Emission Projections for the Clean Air Act Second Section 812 Prospective Analysis. Exhibit 6-4. U.S. EPA Office of Air and Radiation. *Available at*: http://www.epa.gov/oar/sect812/feb11/emissionsfullreport.pdf. (Accessed: February 16, 2015).

IISD (International Institute for Sustainable Development). 2011. Earth Negotiations Bulletin, A Reporting Service for Environment and Development Negotiations: COP17 Final. Last revised: December 13, 2011. *Available at*: http://www.iisd.ca/download/pdf/enb12534e.pdf. (Accessed: June 11, 2014).

IPCC (Intergovernmental Panel on Climate Change). 2000. Special Report on Emission Scenarios. A Special Report from Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Japan, Institute for Global Environmental Strategies.

IPCC. 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge, UK, Cambridge University Press.

IPCC. 2007b. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge, UK, Cambridge University Press.

IPCC. 2007c. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Rood, S.B., G.M. Samuelson, J.K. Weber, and K.A. Wywrot. 2005. Twentieth-Century Decline in Streamflows from the Hydrographic Apex of North America. *Journal of Hydrology* 306:215–233. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2007d. Summary for Policymakers. Pages 1–18 in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA. 996 pgs. *Available at*: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. (Accessed: August 12, 2011).

IPCC. 2010. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change.

IPCC. 2013a. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY.

IPCC. 2013b. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY.

IPCC. 2013b. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Beckley, B. D., N. P. Zelensky, S. A. Holmes, F. G. Lemoine, R. Ray, G. T. Mitchum, S. Desai, and S. Brown. 2010. Assessment of the Jason-2 Extension to the TOPEX/Poseidon, Jason-1 Sea-surface Height Time Series for Global Mean Sea Level Monitoring. *Marine Geodesy* 33:447–471. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2013b. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bond-Lamberty, B., and A. Thomson. 2010. Temperature-associated Increases in the Global Soil Respiration Record. *Nature* 464:579–U132. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2013b. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Groisman, P., R. Knight, T. R. Karl, D. Easterling, B. M. Sun, and J. Lawrimore. 2004. Contemporary Changes of the Hydrological Cycle over the Contiguous United States: Trends Derived from In Situ Observations. J. Hydrometeor. 5:64–85. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2013b. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Marchenko, S. S., V. Romanovsky, and G. S. Tipenko. 2008. Numerical Modeling of Spatial Permafrost Dynamics in 18 Alaska. Ninth International Conference on Permafrost. Cambridge, United Kingdom and New York, NY, Cambridge University Press.

IPCC. 2013b. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nemani, R. R., C. D. Keeling, H. Hashimoto, W. M. Jolly, S. C. Piper, C. J. Tucker, R. B. Myneni, and S. W. Running. 2003. Climate-driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. *Science* 300:1560–1563. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2013c. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2013c. Summary for Policymakers. Page 1–28 in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. *Available at*: http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf. (Accessed: November 13, 2014).

IPCC. 2014a. Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY.

IPCC. 2014a. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Rabassa, J. 2009. Impact of Global Climate Change on Glaciers and Permafrost of South America, with Emphasis on Patagonia, Tierra del Fuego, and the Antarctic Peninsula. *Developments in Earth Surface Processes* 13:415–438. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Seneviratne, S. I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhan. 2012. Changes in Climate Extremes and their Impacts on the Natural Physical Environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press. Cambridge, UK, and New York, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kalra, A., T. C. Piechota, R. Davies, and G. A. Tootle. 2008. Changes in US Streamflow and Western US Snowpack. J*ournal of Hydrologic Engineering* 13(3):156–163. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Dai, A., T. Qian, K. E. Trenberth, and J. D. Milliman. 2009. Changes in Continental Freshwater Discharge from 1948 to 2004. *Journal of Climate* 22(10):2773–2792. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Clow, D. W. 2010. Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. *Journal of Climate* 23(9):2293–2306. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Korhonen, J., and E. Kuusisto. 2010. Long-term Changes in the Discharge Regime in Finland. *Hydrology Research* 41:253–268. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tan, A., J. C. Adam, and D. P. Lettenmaier. 2011. Change in Spring Snowmelt Timing in Eurasian Arctic Rivers. Journal of Geophysical Research-Atmospheres 116:D03101. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Stoll, S., H. J. H. Franssen, R. Barthel, and W. Kinzelbach. 2011. What Can We Learn from Long-term Groundwater Data to Improve Climate Change Impact Studies? Hydrology and Earth System Sciences 15(12):3861–3875. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Portmann, F.T., P. Döll, S. Eisner, and M. Flörke. 2013. Impact of Climate Change on Renewable Groundwater Resources: Assessing the Benefits of Avoided Greenhouse Gas Emissions Using Selected CMIP5 Climate Projections. Environmental Research Letters 8(2):024023. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Crosbie, R. S., B. R. Scanlon, F. S. Mpelasoka, R. C. Reedy, J. B. Gates, and L. Zhang. 2013b. Potential Climate Change Effects on Groundwater Recharge in the High Plains Aquifer, USA. Water Resources Research 49(7):3936–3951. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ng, G.-H.C., D. McLaughlin, D. Entekhabi, and B. R. Scanlon. 2010. Probabilistic Analysis of the Effects of Climate Change on Groundwater Recharge. Water Resources Research 46:W07502. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Pearl H. W., and J. Huisman. 2008. Blooms Like it Hot. Science 320:57–58. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Auld, H., D. MacIver, and J. Klaassen. 2004. Heavy Rainfall and Waterborne Disease Outbreaks: The Walkerton Example. Journal of Toxicology and Environmental Health-Part A-Current Issues 67(20–22):1879–1887. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Curriero, F., J. Patz, J. Rose, and S. Lele. 2001. The Association between Extreme Precipitation and Waterborne Disease Outbreaks in the United States, 1948–1994. *American Journal of Public Health* 91(8):1194–1199. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jean, J.-S., H.-R. Guo, S.-H. Chen, C.-C. Liu, W.-T. Chang, Y.-J. Yang, and M.-C. Huang. 2006. The Association between Rainfall Rate and Occurrence of an Enterovirus Epidemic due to a Contaminated Well. *Journal of Applied Microbiology* 101(6):1224–1231. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Seidu, R., T. A. Stenström, and L. Owe. 2013. A Comparative Cohort Study of the Effect of Rainfall and Temperature on Diarrhoeal Disease in Faecal Sludge and Non-faecal Sludge Applying Communities, Northern Ghana. *Journal of Water and Climate Change* 4(2):90–102. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY **citing** Tumwine, J., A. Kekitiinwa, N. Nabukeera, D. Akiyoshi, M. Buckholt, and S. Tzipori. 2002. Enterocytozoon bieneusi among Children with Diarrhea Attending Mulago Hospital in Uganda. *American Journal of Tropical Medicine and Hygiene* 67(3):299–303.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tumwine, J., A. Kekitiinwa, N. Nabukeera, D. Akiyoshi, S. Rich, G. Widmer, X. Feng, and S. Tzipori. 2003. Cryptosporidium Parvum in Children with Diarrhea in Mulago Hospital, Kampala, Uganda. *American Journal of Tropical Medicine and Hygiene* 68(6):710–715. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Menzel, A., T. H. Sparks, N. Estrella, E. Koch, A. Aasa, R. Ahas, K. Alm-

Kubler, P. Bissolli, O. Braslavska, A. Briede, F. M. Chmielewski, Z. Crepinsek, Y. Curnel, A. Dahl, C. Defila, A. Donnelly, Y. Filella, K. Jatcza, F. Mage, A. Mestre, O. Nordli, J. Penuelas, P. Pirinen, V. Remisova, H. Scheifinger, M. Striz, A. Susnik, A. J. H. Van Vliet, F. E. Wielgolaski, S. Zach, and A. Zust. 2006. European Phenological Response to Climate Change Matches the Warming Pattern. *Global Change Biology* 12(10):1969–1976. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cleland, E. E., I. Chuine, A. Menzel, H. A. Mooney, and M. D. Schwartz. 2007. Shifting Plant Phenology in Response to Global Change. *Trends in Ecology & Evolution* 22(7):357–365. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Parmesan, C. 2007. Influences of Species, Latitudes and Methodologies on Estimates of Phenological Response to Global Warming. *Global Change Biology* 13(9):1860–1872. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Primack, R. B., I. Ibáñez, H. Higuchi, S. D. Lee, A. J. Miller-Rushing, A. M. Wilson, J. A. and Silander Jr. 2009. Spatial and Interspecific Variability in Phenological Responses to Warming Temperatures. *BiologicalConservation* 142(11):2569–2577. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cook, B. I., E. R. Cook, P. C. Huth, J. E. Thompson, A. Forster, and D. Smiley. 2008. A Cross-taxa Phenological Dataset from Mohonk Lake, NY and its Relationship to Climate. *International Journal of Climatology* 28(10):1369–1383. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bedsworth, L. 2009. Preparing for Climate Change: A Perspective from Local Public Health Officers in California. *Environmental Health Perspectives* 117(4):617–623. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Blake, R., A. Grimm, T. Ichinose, R. Horton, S. Gaffin, S. Jiong, D. Bader, and L. Cecil. 2011. Urban Climate: Processes, Trends, and Projections. In: Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bonazza, A., P. Messina, C. Sabbioni, C.M. Grossi, and P.

Brimblecombe. 2009. Mapping the Impact of Climate Change on Surface Recession of Carbonate Buildings in Europe. *Science of the Total Environment* 407(6):2039–2050. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Brody, S., H. Grover, E. Lindquist, and A. Vedlitz. 2010. Examining Climate Change Mitigation and Adaptation Behaviours among Public Sector Organisations in the USA. *Local Environment* 15(6):591–603. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Campbell-Lendrum, D., and C. Corvalan. 2007. Climate Change and Developing-Country Cities: Implications for Environmental Health and Equity. *Journal of Urban Health* 84(1):109–117. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Carbognin, L., P. Teatini, A. Tomasin, and L. Tosi. 2010. Global Change and Relative Sea Level Rise at Venice: What Impact in Term of Flooding. *Climate Dynamics* 35(6):1039–1047. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** de Lucena, A. F. P., A. S. Szklo, R. Schaeffer, R. R. de Souza, B. S. M. C. Borba, I. V. L. da Costa, A. O. P. Júnior, and S. H. F. da Cunha. 2009. The Vulnerability of Renewable Energy to Climate Change in Brazil. *Energy Policy* 37(3):879–889. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** de Lucena, A. F. P., R. Schaeffer, and A. S. Szklo. 2010. Least-cost Adaptation Options for Global Climate Change Impacts on the Brazilian Electric Power System. *Global Environmental Change* 20(2):342–350. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** de Sherbinin, A., A. Schiller, and A. Pulsipher. 2007. The Vulnerability of Global Cities to Climate Hazards. *Environment and Urbanization* 19(1):39–64. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Dossou, K. M. R., and B. Gléhouenou-Dossou. 2007. The Vulnerability to Climate Change of Cotonou (Benin): The Rise in Sea Level. *Environment and Urbanization* 19(1):65–79. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** El Banna, M. M., and O. E. Frihy. 2009. Natural and Anthropogenic Influences in the Northeastern Coast of the Nile Delta, Egypt. *Environmental Geology* 57(7):1593–1602. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Fane, S., and A. Turner. 2010. Integrated Water Resource Planning in the Context of Climate Uncertainty. *Water Science and Technology: Water Supply* 10(4):487–494. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Farley, K. A., C. Tague, and G. E. Grant. 2011. Vulnerability of Water Supply from the Oregon Cascades to Changing Climate: Linking Science to Users and Policy. *Global Environmental Change* 21(1):110–122. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Finland Safety Investigations Authority. 2011. S2/2010Y The Storms of July–August 2010. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Früh, B., P. Becker, T. Deutschländer, J. Hessel, M. Kossmann, I. Mieskes, J. Namyslo, M. Roos, U. Sievers, and T. Steigerwald. 2011. Estimation of Climate-change Impacts on the Urban Heat Load Using an Urban Climate Model and Regional Climate Projections. *Journal of Applied Meteorology and Climatology* 50(1):167–184. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gamble, J., M. Stevenson, E. McClean, and L. G. Heaney. 2009. The Prevalence of Nonadherence in Difficult Asthma. *American Journal of Respiratory and Critical Care Medicine* 180(9):817–822. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gober, P. 2010. Desert Urbanization and the Challenges of Water Sustainability. *Current Opinion in Environmental Sustainability* 2(3):144–150. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Grimmond, C. S. B. 2011. Climate of Cities. In: Routledge Handbook

of Urban Ecology. Routledge. Abingdon, VA. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Grossi, C. M., P. Brimblecombe, and I. Harris. 2007. Predicting Long Term Freeze–Thaw Risks on Europe Built Heritage and Archaeological Sites in a Changing Climate. *Science of the Total Environment* 377(2–3):273–281. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Haines, A., N. Bruce, S. Cairncross, M. Davies, K. Greenland, A. Hiscox, S. Lindsay, T. Lindsay, D. Satterthwaite, and P. Wilkinson. 2013. Promoting Health and Advancing Development through Improved Housing in Low-income Settings. *Journal of Urban Health* 90(5):810–831. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hajat, S., M. O'Connor, and T. Kosatsky. 2010. Health Effects of Hot Weather: From Awareness of Risk Factors to Effective Health Protection. *The Lancet* 375(9717):856–863. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hallegatte, S., C. Green, R. J. Nicholls, and J. Corfee-Morlot. 2013. Future Flood Losses in Major Coastal Cities. *Nature Climate Change* 3(9):802–806. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Halsnæs, K., and A. Garg. 2011. Assessing the Role of Energy in Development and Climate Policies—Conceptual Approach and Key Indicators. *World Development* 39(6):987–1001. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hammer, S., J. Keirstead, S. Dhakal, J. Mitchell, M. Coley, R. Connell, R. Gonzalez, L. Herve-Mignucci, L. Parshall, N. Schulz, and M. Hyams. 2011. Climate Change and Urban Energy Systems. In: Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hanson, S., R. Nicholls, N. Ranger, S. Hallegatte, J. Corfee-Morlot, C. Herweijer, and J. Chateau. 2011. A Global Ranking of Port Cities with High Exposure to Climate

Extremes. *Climatic Change* 104(1):89–111. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Herrfahrdt-Pähle, E. 2010. South African Water Governance between Administrative and Hydrological Boundaries. *Climate and Development* 2(2):111–127. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Howard, G., K. Charles, K. Pond, A. Brookshaw, R. Hossain, and J. Bartram. 2010. Securing 2020 Vision for 2030: Climate Change and Ensuring Resilience in Water and Sanitation Services. *Journal of Water and Climate Change* 1(1):2–16. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** IFRC. 2010. World Disasters Report 2010: Focus on Urban Risk. International Federation of Red Cross and Red Crescent Societies. Geneva, Switzerland. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** IPCC. 2013a. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jacob, D. J., and D. A. Winner. 2009. Effect of Climate Change on Air Quality. *Atmospheric Environment* 43(1):51–63. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jacob, K., G. Deodatis, J. Atlas, M. Whitcomb, M. Lopeman, O. Markogiannaki, Z. Kennett, A. Morla, R. Leichenko, and P. Ventura. 2011. Transportation. In: Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Technical Report. New York State Energy Research and Development Authority (NYSERDA). Albany, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jacobs, K., and S. Williams. 2011. What to Do Now? Tensions and Dilemmas in Responding to Natural Disasters: A Study of Three Australian State Housing Authorities.

International Journal of Housing Policy 11(2):175–193. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jha, A. K., R. Bloch, and J. Lamond. 2012. Cities and Dlooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century. World Bank Publications. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Johansson, T. B., N. Nakicenovic, A. Patwardhan, and L., and Gomez-Echeverri (eds.). 2012. Global Eenergy Assessment: Toward a Sustainable Future. Cambridge University Press. New York, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jollands, N., M. Ruth, C. Bernier, and N. Golubiewski. 2007. The Climate's Long-term Impact on New Zealand Infrastructure (CLINZI) Project—A Case Study of Hamilton City, New Zealand. *Journal of Environmental Management* 83(4):460–477. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kinney, P. L. 2008. Climate Change, Air Quality, and Human Health. *American Journal of Preventive Medicine* 35(5):459–467. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kithiia, J., and A. Lyth. 2011. Urban Wildscapes and Green Spaces in Mombasa and their Potential Contribution to Climate Change Adaptation and Mitigation. *Environment and Urbanization* 23(1):251–265. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lemonsu, A., R. Kounkou-Arnaud, J. Desplat, J. Salagnac, and V. Masson. 2013. Evolution of the Parisian Urban Climate under a Global Changing Climate. *Climatic Change* 116(3–4):679–692. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Love, G., A. Soares, and H. Püempel. 2010. Climate Change, Climate Variability and Transportation. *Procedia Environmental Sciences* 1(0):130–145. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Maller, C. J., and Y. Strengers. 2011. Housing, Heat Stress and Health in a Changing Climate: Promoting the Adaptive Capacity of Vulnerable Households, A Suggested Way Forward. *Health Promotion International* 26(4):492–498. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McCarthy, M. P., M. J. Best, and R. A. Betts. 2010. Climate Change in Cities due to Global Warming and Urban Effects. *Geophysical Research Letters* 37(9):L09705. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McDonald, R. I., P. Green, D. Balk, B. M. Fekete, C. Revenga, M. Todd, and M. Montgomery. 2011. Urban Growth, Climate Change, and Freshwater Availability. *Proceedings of the National Academy of Sciences* 108(15):6312–6317. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McMichael, A., S. Friel, A. Nyong, and C. Corvalan. 2008. Global Environmental Change and Health: Impacts, Inequalities, and the Health Sector. *BMJ: British Medical Journal* 336(7637):191. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mideksa, T. K., and S. Kallbekken. 2010. The Impact of Climate Change on the Electricity Market: A Review. *Energy Policy* 38(7):3579–3585. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mirasgedis, S., Y. Sarafidis, E. Georgopoulou, V. Kotroni, K. Lagouvardos, and D. Lalas. 2007. Modeling Framework for Estimating Impacts of Climate Change on Electricity Demand at Regional Level: Case of Greece. *Energy Conversion and Management* 48(5):1737–1750. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mitlin, D., and D. Satterthwaite. 2013. Urban Poverty in the Global South: Scale and Nature. London, UK: Routledge. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Muller, M. 2007. Adapting to Climate Change: Water Management for Urban Resilience. *Environment and Urbanization* 19(1):99–113. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** O'Neill, M. S., and K. L. Ebi. 2009. Temperature Extremes and Health: Impacts of Climate Variability and Change in the United States. *Journal of Occupational and Environmental Medicine* 51(1):13–25. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Oleson, K. 2012. Contrasts between Urban and Rural Climate in CCSM4 CMIP5 Climate Change Scenarios. *Journal of Climate* 25(5):1390–1412. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Prowse, T. D., C. Furgal, R. Chouinard, H. Melling, D. Milburn, and S. L. Smith. 2009. Implications of Climate Change for Economic Development in Northern Canada: Energy, Resource, and Transportation Sectors. *AMBIO: A Journal of the Human Environment* 38(5):272–281. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Reid, C. E., M. S. O'Neill, C. J. Gronlund, S. J. Brines, D. G. Brown, A. V. Diez-Roux, and J. Schwartz. 2009. Mapping Community Determinants of Heat Vulnerability. *Environmental Health Perspective*s 117(11):1730–1736. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Romero-Lankao, P. 2010. Water in Mexico City: What Will Climate Change Bring to its History of Water-related Hazards and Vulnerabilities? *Environment and Urbanization* 22(1):157–178. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Rosenberg, E. A., P. W. Keys, D. B. Booth, D. Hartley, J. Burkey, A. C. Steinemann, and D. P. Lettenmaier. 2010. Precipitation Extremes and the Impacts of Climate Change on Stormwater Infrastructure in Washington State. *Climatic Change* 102(1):319–349. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Roy, S. B., L. Chen, E. H. Girvetz, E. P. Maurer, W. B. Mills, and T. M. Grieb. 2012. Projecting Water Withdrawal and Supply for Future Decades in the US under Climate Change Scenarios. *Environmental Science & Technology* 46(5):2545–2556. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Satterthwaite, D., and A. Sverdlik. 2012. Energy Access and Housing for Low-income Groups in Urban Areas. In: Energizing Sustainable Cities: Assessing Urban Energy. Earthscan. London, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Savonis, M. J., V. R. Burkett, and J. R. Potter. 2008. Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. US Climate Change Science Program. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Schaeffer, R., A. S. Szklo, A. F. Pereira de Lucena, B. S. Moreira Cesar Borba, L. P. Pupo Nogueira, F. P. Fleming, A. Troccoli, M. Harrison, and M. S. Boulahya. 2011. Energy Sector Vulnerability to Climate Change: A Review. *Energy* 38(1):1–12. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Smith, B. J., M. Gomez-Heras, and S. McCabe. 2008. Understanding the Decay of Stone-built Cultural Heritage. *Progress in Physical Geography* 32(4):439–461. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Stewart, M. G., X. Wang, and M. N. Nguyen. 2011. Climate Change Impact and Risks of Concrete Infrastructure Deterioration. *Engineering Structures* 33(4):1326–1337. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tait, S.J., R. M. Ashley, A. Cashman, J. Blanksby, and A. J. Saul. 2008. Sewer System Operation into the 21st Century, Study of Selected Responses from a UK Perspective. *Urban Water Journa*l 5(1):79–88 Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Thornbush, M., and H. Viles. 2007. Simulation of the Dissolution of Weathered versus Unweathered Limestone in Carbonic Acid Solutions of Varying Strength. *Earth Surface Processes and Landform*s 32(6):841–852. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tidwell, V. C., P. H. Kobos, L. A. Malczynski, G. Klise, and C. R. Castillo. 2012. Exploring the Water-thermoelectric Power Nexus. *Journal of Water Resources Planning and Management* 138(5):491–501. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tubby, K., and J. Webber. 2010. Pests and Diseases Threatening Urban Trees under a Changing Climate. *Forestry* 83(4):451–459. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** United Nations. 2009. Global Assessment Report on Disaster Risk Reduction: Risk and Poverty in a Changing Climate. ISDR. Geneva, Switzerland. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** United Nations. 2011. Revealing Risk, Redefining Development: The 2011 Global Assessment Report on Disaster Risk Reduction. United Nations International Strategy for Disaster Reduction. Geneva, Switzerland. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** United Nations. 2012. World Urbanization Prospects: The 2012 Revision. UN Department of Economic and Social Affairs, Population Division. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Vairavamoorthy, K., S. D. Gorantiwar, and A. Pathirana. 2008. Managing Urban Water Supplies in Developing Countries—Climate Change and Water Scarcity Scenarios. *Physics and Chemistry of the Earth, Parts A/B/C* 33(5):330–339. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Aerts, J. C. J. H., W. J. W. Botzen, H. de Moel, and M. Bowman. 2013. Cost Estimates for Flood Resilience and Protection Strategies in New York City. *Annals of the New York Academy of Sciences* 1294:1–104. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Allen, C.D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D.D. Breshears, E. H. Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J. H. Lim, G. Allard, S. W. Running, A. Semerci, and N.

Cobb. 2010. A Global Overview of Drought and Heat-induced Tree Mortality Reveals Emerging Climate Change Risks for Forests. *Forest Ecology and Management* 259(4):660–684. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Allen, D. M., A. J. Cannon, M. W. Toews, and J. Scibek. 2010. Variability in Simulated Recharge Using Different GCMs. Water Resources Research 46:W00F03. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Anderegg, W. R. L., J. M. Kane, and L. D. L. Anderegg. 2013. Consequences of Widespread Tree Mortality Triggered by Drought and Temperature Stress. Nature Climate Change 3(1):30–36. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** André, G., B. Engel, P. Berentsen, T. V. Vellinga, and A. Oude Lansink. 2011. Quantifying the Effect of Heat Stress on Daily Milk Yield and Monitoring Dynamic Changes Using an Adaptive Dynamic Model. *Journal of Dairy Science* 94:4502–4513. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Arneth, A., S. P. Harrison, S. Zaehle, K. Tsigaridis, S. Menon, P. J. Bartlein, J. Feichter, A. Korhola, M. Kulmala, D. O'Donnell, G. Schurgers, S. Sorvari., and T. Vesala. 2010. Terrestrial Biogeochemical Feedbacks in the Climate System. Nature Geoscience 3(8):525–532. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Arrigo, K. R., and G. L. van Dijken. 2011. Secular Trends in Arctic Ocean Net Primary Production. Journal of Geophysical Research 116(C9):C09011. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The Value of Estuarine and Coastal Ecosystem Services. Ecological Monographs 81:169–193. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Beck, M. W., R. D. Brumbaugh, L. Airoldi, A. Carranza, L. D. Coen, C. C. O. Defeo, G. J. Edgar, B. Hancock, M. C. Kay, H. S. Lenihan, M. W. Luckenbach, C. L. Toropova, G. Zhang and X. Guo. 2011. Oyster Reefs at Risk and Recommendations for Conservation, Restoration

and Management. BioScience 61:107–116. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Becker, A., S. Inoue, M. Fischer, and B. Schwegler. 2012. Climate Change Impacts on International Seaports: Knowledge, Perceptions and Planning Efforts among Port Administrators. Climate Change 110(1):5–29. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Becker, A. H., M. Acciaro, R. Asariotis, E. Cabrera, L. Cretegny, P. Crist, M. Esteban, A. Mather, S. Messner, S. Naruse, A. K. Y. Ng, S. Rahmstorf, M. Savonis, D. Song, V. Stenek, and A. F. Velegrakis. 2013. A Note on Climate Change Adaptation for Seaports: A Challenge for Global Ports, a Challenge for Global Society. Climatic Change 120:683–695. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bellard, C., C. Bertelsmeier, P. Leadley, W. Thuiller, and F. Courchamp. 2012. Impacts of Climate Change on the Future of Biodiversity. Ecology Letters 15(4):365–377. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Boateng, I. 2010. Spatial Planning in Coastal Regions: Facing the Impact of Climate Change. International Federation of Surveyors. Copenhagen, Denmark. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bollmann, M., T. Bosch, F. Colijn, R. Ebinghaus, R. Froese, K. Güssow, S. Khalilian, S. Krastel, A. Körtzinger, M. Langenbuch, M. Latif, B. Matthiessen, F. Melzner, A. Oschlies, S. Petersen, A. Proelß, M. Quaas, J. Reichenbach, T. Requate, T. Reusch, P. Rosenstiel, J. O. Schmidt, K. Schrottke, H. Sichelschmidt, U. Siebert, R. Soltwedel, U. Sommer, K. Stattegger, H. Sterr, R. Sturm, T. Treude, A. Vafeidis, C. van Bernem, J. van Beusekom, R. Voss, M. Visbeck, M. Wahl, K. Wallmann, and F. Weinberger. 2010. World Ocean Review 2010. Maribus, Hamburg. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Brander, K. M. 2007. Global Fish Production and Climate Change. Proceedings of the National Academy of Sciences 104:19709–19714. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Briffa, K. R., V. V. Shishov, T. M. Melvin, E. A. Vaganov, H. Grudd, R. M. Hantemirov, M. Eronen, and M. M. Naurzbaev. 2008. Trends in Recent Temperature and Radial Tree Growth Spanning 2000 Years across Northwest Eurasia. Philosophical Transactions of the Royal Society B-Biological Sciences 363(1501):2271–2284. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Canadell, J. G., C. Le Quéré, M. R. Raupach, C. B. Field, E. T. Buitenhuis, P. Ciais, T. J. Conway, N. P. Gillett, R. A. Houghton, G. and Marland. 2007. Contributions to Accelerating Atmospheric CO2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks. Proceedings of the National Academy of Sciences 104(47):18866–18870. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Carnicer, J., M. Coll, M. Ninyerola, X. Pons, G. Sanchez, and J. Penuelas. 2011. Widespread Crown Condition Dcline, Food Web Disruption, and Amplified Tree Mortality with Increased Climate Change-type Drought. Proceedings of the National Academy of Sciences of the United States of America 108(4):1474–1478. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** CCSP. 2008a. Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Transportation, Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cheung, W., V. Lam, J. Sarmiento, K. Kearney, R. Watson, D. Zeller and D. Pauly. 2010. Large Scale Redistribution of Maximum Fisheries Catch in the Global Ocean under Climate Change. Global Change Biology 16(1):24–35. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cheung, W. L., R. Watson, and D. Pauly. 2013. Signature of Ocean Warming in Global Fisheries Catch. Nature 497:365–368. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Chisolm, E. I., and J. C. Matthews. 2012. Impact of Hurricanes and Flooding on Buried Infrastructure. Leadership and Management in Engineering 12(3):151–156. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cook, B. I., E. M. Wolkovich, and C. Parmesan. 2012b. Divergent Responses to Spring and Winter Warming Drive Community Level Flowering Trends. Proceedings of the National Academy of Sciences of the United States of America 109:9000–9005. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cook, B.I., E. M. Wolkovich, T. J. Davies, T. R. Ault, J. L. Betancourt, J. M. Allen, K. Bolmgren, E. E. Cleland, T. M. Crimmins, N. J. B. Kraft, L. T. Lancaster, S. J. Mazer, G. J. McCabe, B. J. McGill, C. Parmesan, S. Pau, J. Regetz, N. Salamin, M. D. Schwartz, and S. E. Travers. 2012a. Sensitivity of Spring Phenology to Warming across Temporal and Spatial Climate Gradients in Two Independent Databases. Ecosystems 15(8):1283–1294. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cook, R. M., and M. R. Heath. 2005. The Implications of Warming Climate for the Management of North Sea Demersal Fisheries. ICES Journal of Marine Science 62:1322–1326. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Craine, J. M., A. J. Elmore, K. C. Olson, and D. Tolleson. 2010. Climate Change and Cattle Nutritional Stress. Global Change Biology 16:2901–2911. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Dawson, T. P., S. T. Jackson, J. I. House, I. C. Prentice, and G. M. Mace. 2011. Beyond Predictions: Biodiversity Conservation in a Changing Climate. Science 332(6025):53–58. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** de Sherbinin, A., M. Castro, F. Gemenne, M. M. Cernea, S. Adamo, P. M. Fearnside, G. Krieger, S. Lahmani, A. Oliver-Smith, A. Pankhurst, T. Scudder, B. Singer, Y. Tan, G. Wannier, P. Boncour, C. Ehrhart, G. Hugo, B. Pandey, G. Shi. 2011. Preparing for Resettlement Associated with Climate Change. Science 334:456–457. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Duguy, B., S. Paula, J. G. Pausas, J. A. Alloza, T. Gimeno, and R. V. Vallejo. 2013. Effects of Climate and Extreme Events on Wildfire Regime and their Ecological Impacts. In: Regional Assessment of Climate Change in the Mediterranean. Springer, pgs. 101–134. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Durack, P. J., S. E. Wijffels, and R. J. Matear. 2012. Ocean Salinities Reveal Strong Global Water Cycle Intensification during 1950 to 2000. Science 336(6080):455–458. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Etheridge D. M., L. P. Steele, R. J. Francey, and R. L. Langenfelds. 2002. Historical CH4 Records since about 1000 A.D. from Ice Core Data. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory. U.S. Department of Energy. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Etheridge D. M., L. P. Steele, R. L. Langenfelds, R. J. Francey, J.-M. Barnola, and V. I. Morgan. 1996. Natural and Anthropogenic Changes in Atmospheric CO2 over the Last 1000 Years from Air in Antarctic Ice and Firn. Journal of Geophysical Research: Atmospheres 101:4115–4128. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** FAO, WFP, and IFAD. 2012. The State of Food Insecurity in the World 2012. Economic Growth Is Necessary but not Sufficient to Accelerate Reduction of Hunger and Malnutrition. FAO. Rome, Italy. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gaffin, S. R., C. Rosenzweig, and A. Y. Kong. 2012. Adapting to Climate Change through Urban Green Infrastructure. Nature Climate Change 2(10):704–704. Cambridge, United Kingdom and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Handmer, J., Y. Honda, Z. W. Kundzewicz, N. Arnell, G. Benito, J. Hatfield, I. F. Mohamed, P. Peduzzi, S. Wu, B. Sherstyukov, K. Takahashi, and Z. Yan. 2012. Changes in Impacts of Climate Extremes: Human Systems and Ecosystems. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hanson. S., and R. J. Nicholls. 2012. Extreme Flood Events and Port Cities through the Twenty-First Century. Maritime Transport and the Climate Change Challenge. Earthscan/Routledge, New York. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hoegh-Guldberg, O. 2011. Coral Reef Ecosystems and Anthropogenic Climate Change. Regional Environmental Change 11:215–227. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hogg, E. H., J. P. Brandt, and M. Michaelian. 2008. Impact of a Regional Drought on the Productivity, Dieback and Biomass of Western Canadian Aspen Forests. Canadian Journal of Forest Research 38:1373–1384. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Horton, R., V. Gornitz, M. Bowman, and R. Blake. 2010. Climate Observations and Projections. Annals of the New York Academy of Sciences 1196(1):41–62. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Høye, T.T., E. Post, H. Meltofte, N. M. Schmidt, and M. C. Forchhammer. 2007. Rapid Advancement of Spring in the High Arctic. Current Biology CB 17(12):R449–R451. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Iqbal, M. M., M. A. Goheer, and A. M. Khan. 2009. Climate-change Aspersions on Food Security of Pakistan. Science Vision 15(1):15–23. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Izaurralde, R. C., A. M. Thomson, J. A. Morgan, P. B. Fay, H. W. Polley, and J. L. Hatfield. 2011. Climate Impacts on Agriculture: Implications for Forage and Rangeland Production. Agronomy Journal 103 (2):371–381. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Linham, M. M., and R. J. Nicholls. 2010. Technologies for Climate Change Adaptation: Coastal Erosion and Flooding. UNEP Risø Centre on Energy, Climate and Sustainable Development. Roskilde, Denmark. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Liu, J., C. Folberth, H. Yang, J. Röckström, K. Abbaspour, and A. J.

Zehnder. 2013. A Global and Spatially Explicit Assessment of Climate Change Impacts on Crop Production and Consumptive Water Use. PLoS ONE 8(2):e57750. Cambridge, United Kingdom and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ma, T., and C. G. Zhou. 2012. Climate-associated Changes in Spring Plant Phenology in China. International Journal of Biometeorology 56(2):269–275. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McGranahan, G., D. Balk, and B. Anderson 2007. The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones. Environment and Urbanization 19:17–37. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** NRC (National Research Council of the National Academies). 2010b. Advancing the Science of Climate Change, Report in Brief. National Research Council. National Academies Press. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Peñuelas, J., J. Sardans, M. Estiarte, R. Ogaya, J. Carnicer, M. Coll, A. Barbeta, A. Rivas-Ubach, J. Llusia, M. Garbulsky, I. Filella, A. S. and Jump. 2013. Evidence of Current Impact of Climate Change on Life: A Walk from Genes to the Biosphere. Global Change Biology 19(8):2303–2338. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Raffa, K. F., B. H. Aukema, B. J. Bentz, A. L. Carroll, J. A. Hicke, M. G. Turner, and W. H. Romme. 2008. Crossscale Drivers of Natural Disturbances Prone to Anthropogenic Amplification: The Dynamics of Bark Beetle Eruptions. Bioscience 58(6):501–517. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Rosenzweig, C., and W. Solecki (eds.).2010. Climate Change Adaptation in New York City: Building a Risk Management Response. New York City Panel on Climate Change 2010 Report. Annals of the New York Academy of Sciences 1196:1–354. Cambridge, United Kingdom and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Schmitt, K., T. Albers, T. T. Pham, and S. C. Dinh. 2013. Site-specific and Integrated Adaptation to Climate Change in the Coastal Mangrove Zone of Soc Trang Province,

Vietnam. Journal of Coastal Conservation 17(3):545–558. Cambridge, United Kingdom and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Thorup, K., A. P. Tøttrup, and C. Rahbek, C. 2007. Patterns of Phenological Changes in Migratory Birds. Oecologia 151(4):697–703. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Adam, C. 2013 Coping with Adversity: The Macroeconomic Management of Natural Disasters. Environmental Science and Policy 27(Supp1):S99–S111. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Adams, H., and W. N. Adger. 2013. The Contribution of Ecosystem Services to Place Utility as a Determinant of Migration Decision-making. Environmental Research Letters 8(1):015006. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Adams, V., T. V. Hattum, and D. English. 2009. Chronic Disaster Syndrome: Displacement, Disaster Capitalism, and the Eviction of the Poor from New Orleans. American Ethnologist 36(4):615–636. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Alonso, D., M. J. Bouma, and M. Pascual. 2011. Epidemic Malaria and Warmer Temperatures in Recent Decades in an East African Highland. Proceedings of the Royal Society B: Biological Sciences 278(1712):1661–1669. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Anderson, M., L. Holcombe, and D. Williams. 2007. Reducing Landslide Risk in Areas of Unplanned Housing in the Caribbean—A Government-Community Partnership Model. Journal of International Development 19(2):205–221. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Anderson, S., J. Morton, and C. Toulmin. 2010. Climate Change for Agrarian Societies in Drylands: Implications and Future Pathways. In: Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World. Washington, DC World Bank. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Armitage, D., F. Berkes, A. Dale, E. Kocho-Schellenberg, and E. Patton. 2011. Co-management and the Coproduction of Knowledge: Learning to Adapt in Canada's Arctic. Global Environmental Change 21(3):995–1004. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Arnall, A. 2013. A Climate of Control: Flooding, Displacement and Planned Resettlement in the Lower Zambezi River Valley, Mozambique. Geographical Journal. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Asian Development Bank (ADB). 2012. Addressing Climate Change and Migration in Asia and the Pacific. Mandaluyong City, Philippines. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Athanassiadou, M., J. Baker, D. Carruthers, W. Collins, S. Girnary, D. Hassell, M. Hort, C. Johnson, K. Johnson, and R. Jones. 2010. An Assessment of the Impact of Climate Change on Air Quality at Two UK Sites. Atmospheric Environment 44(15):1877–1886. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Auffhammer, M. 2011. Agriculture: Weather Dilemma for African Maize. Nature Climate Change 1:27–28. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Babel, M., A. Gupta, and N. Domingo. 2006. Land Subsidence: A Consequence of Groundwater Over-exploitation in Bangkok, Thailand. International Review for Environmental Strategies 6(2):307–327. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Barata, M., E. Ligeti, G. De Simone, T. Dickinson, D. Jack, J. Penney, M. Rahman, and R. Zimmerman. 2011. Climate Change and Human Health in Cities. In: Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Barbieri, A. F., E. Domingues, B. L. Queiroz, R. M. Ruiz, J. I. Rigotti, J. A. M. Carvalho, and M. F. Resende. 2010. Climate Change and Population Migration in Brazil's Northeast: Scenarios for 2025–2050. Population and Environment 31(5):344–370. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Barnett, J., and W. N. Adger. 2003. Climate Dangers and Atoll Countries. Climatic Change 61(3):321–337. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Beaumier, M. C., and J. D. Ford. 2010. Food Insecurity among Inuit Women Exacerbated by Socioeconomic Stresses and Climate Change. Canadian Journal of Public Health 101(3):196–201. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Beggs, P. J. 2010. Adaptation to Impacts of Climate Change on Aeroallergens and Allergic Respiratory Diseases. International Journal of Environmental Research and Public Health 7(8):3006–3021. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Belanger, D., P. Gosselin, P. Valois, S. Germain, and B. Abdous. 2009. Use of a Remote Car Starter in Relation to Smog and Climate Change Perceptions: A Population Survey in Quebec (Canada). International Journal of Environmental Research and Public Health 6(2):694–709. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bergholt, D., and P. Lujala. 2012. Climate-related Natural Disasters, Economic Growth, and Armed Civil Conflict. Journal of Peace Research 49(1):147–162. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bernauer, T., T. Böhmelt, and V. Koubi. 2012. Environmental

Changes and Violent Conflict. Environmental Research Letters 7(1):015601. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Black, R., S. R. G. Bennett, S. M. Thomas, and J. R. Beddington. 2011. Climate Change: Migration as Adaptation. Nature 478(7370):447–449. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Blattman, C., and E. Miguel. 2010. Civil War. Journal of Economic Literature 48(1):3–57. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bronen, R. 2010: Forced Migration of Alaskan Indigenous Communities due to Climate Change. In: Environment, Forced Migration and Social Vulnerability. Springer, Berlin. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bronen, R. 2011. Climate-induced Community Relocations: Creating an Adaptive Governance Framework Based in Human Rights Doctrine. New York University Review of Law and Social Change 35:357. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Bronen, R., and F. S. Chapin. 2013. Adaptive Governance and Institutional Strategies for Climate-induced Community Relocations in Alaska. Proceedings of the National Academy of Sciences 100:9320–9325. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Brown, H. C. 2009. Climate Change and Ontario Forests: Prospects for Building Institutional Adaptive Capacity. Mitigation and Adaptation Strategies for Global Change 14(6):513–536. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Castro, A. P., D. Taylor, and D. W. Brokensha. 2012. Climate Change and Threatened Communities: Vulnerability, Capacity, and Action. Bourton on Dunsmore, UK. Practical Action Publishing. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Chang, H. H., J. Zhou, and M. Fuentes. 2010. Impact of Climate Change on Ambient Ozone Level and Mortality in Southeastern United States. International Journal

of Environmental Research and Public Health 7(7):2866–2880. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Christidis, N., P. A. Stott, G. S. Jones, H. Shiogama, T. Nozawa, and J. Luterbacher. 2012. Human Activity and Anomalously Warm Seasons in Europe. International Journal of Climatology 32(2):225–239. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Collier, P., G. Conway, and T. Venables. 2008. Climate Change and Africa. Oxford Review of Economic Policy 24(2):337–353. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Collins, T. 2008. The Political Ecology of Hazard Vulnerability: Marginalization, Facilitation and the Production of Differential Risk to Urban Wildfires in Arizona's White Mountains. Journal of Political Ecology 15(21):43. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Delucchi, M. A. 2010. Impacts of Biofuels on Climate Change, Water Use, and Land Use. Annals of the New York Academy of Sciences 1195:28–45. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Easterling, W., P. Aggarwal, P. Batima, K. Brander, L. Erda, M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, S. Schmidhuber, and F. Tubiello. 2007. Food, Fibre and Forest Products. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York, NY. Cambridge University Press. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ebi, K. L., and D. Mills. 2013. Winter Mortality in a Warming World: A Re-assessment. WIREs Climate Change 4:203–212. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ebi, K. L., and G. McGregor. 2008. Climate Change, Tropospheric Ozone and Particulate Matter, and Health Impacts. Environmental Health Perspectives 116(11):1449–1455. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ericksen, P., J. de Leeuw, Thornton P., M. Said, M. Herrero, and A. Notenbaert. 2012. Climate Change in Sub-Saharan Africa: What Consequences for Pastoralism? In: Pastoralism and Development in Africa: Dynamic Change at the Margins. First Edition. New York, NY: Routledge. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Eriksen, S. H., and K. O'Brien. 2007. Vulnerability, Poverty and the Need for Sustainable Adaptation Measures. Climate Policy 7(4):337–352. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Falloon, P., and R. Betts. 2010. Climate Impacts on European Agriculture and Water Management in the Context of Adaptation and Mitigation—The Importance of an Integrated Approach. Science of the Total Environment 408(23):5667–5687. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Fisher, M., M. Chaudhury, and B. McCusker. 2010. Do Forests Help Rural Households Adapt to Climate Variability? Evidence from Southern Malawi. World Development 38(9):1241–1250. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ford, J. D. 2009. Sea Ice Change in Arctic Canada: Are there Limits to Inuit Adaptation? In: Adapting to Climate Change: Thresholds, Values, Governance. First Edition. New York, NY. Cambridge University Press. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Fouillet, A., G. Rey, V. Wagner, K. Laaidi, P. Empereur-Bissonnet, A. Le Tertre, P. Frayssinet, P. Bessemoulin, F. Laurent, P. De Crouy-Chanel, E. Jougla, and D. Hémon. 2008. Has the Impact of Heat Waves on Mortality Changed in France since the European Heat Wave of Summer 2003? A Study of the 2006 Heat Wave. International Journal of Epidemiology 37(2):309–317. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Fraser, E. D. G., A. J. Dougill, K. Hubacek, C. H. Quinn, J. Sendzimir, and M. Termansen. 2011. Assessing Vulnerability to Climate Change in Dryland Livelihood Systems: Conceptual Challenges and Interdisciplinary Solutions. Ecology and Society 16(3):3. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Furgal, C., and T. Prowse. 2008. Northern Canada. In: From Impacts to Adaptation: Canada in a Changing Climate. Ottawa, Canada. Government of Canada. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gatto, J., B. Kim, P. Mahdavi, H. Namekawa, and H. Tran. 2009. The Future Impact of Climate Change on the California Wine Industry and Actions the State of California Should Take to Address it. Stanford, CA. International Policy Studies Program, Stanford University. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gay, C., F. Estrada, C. Conde, H. Eakin, and L. Villers. 2006. Potential Impacts of Climate Change on Agriculture: A Case Study of Coffee Production in Veracruz, Mexico. Climatic Change 79(3–4):259–288. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gray, J. S., H. Dautel, A. Estrada-Pena, O. Kahl, and E. Lindgren. 2009. Effects of Climate Change on Ticks and Tickborne Diseases in Europe. Interdisciplinary Perspectives on Infectious Diseases 2009(593232):1–12. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Haim, D., M. Shechter, and P. Berliner. 2008. Assessing the Impact of Climate Change on Representative Field Crops in Israeli Agriculture: A Case Study of Wheat and Cotton. Climatic Change 86(3–4):425–440. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hassan, R. 2010. The Double Challenge of Adapting to Climate Change while Accelerating Development in Sub-Saharan Africa. Environment and Development Economics 15:661–685. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hein, L., M. J. Metzger, and R. Leemans. 2009. The Local Impacts of Climate Change in the Ferlo, Western Sahel. Climatic Change 93(3–4):465–483. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Immerzeel, W. W., L. P. H. Van Beek, and M. F. P. Bierkens. 2010.

Climate Change Will Affect the Asian Water Towers. Science 328(5984):1382–1385. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** IPCC. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A special report of working groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kinney, P. L., M. Pascal, R. Vautard, and K. Laaidi. 2012. La Mortalite Hivernale va-t-elle Diminuer avec le Changement Climatique? [Winter mortality in a changing climate: will it go down?]. Bull Epidemiol Hebd (12–13):149–151. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kirshen, P., K. Knee, and M. Ruth. 2008. Climate Change and Coastal Flooding in Metro Boston: Impacts and Adaptation Strategies. Climatic Change 90:453–473. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kjellstrom, T., B. Lemke, and O. Hyatt. 2011. Increased Workplace Heat Exposure due to Climate Change. Asia-Pacific Newsletter on Occupational Health and Safety (18):6–20. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kjellstrom, T., I. Holmer, and B. Lemke. 2009. Workplace Heat Stress, Health and Productivity—An Increasing Challenge for Low and Middle-income Countries during Climate Change. Global Health Action 2(1):6. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Klint L. M., E. Wong., M. Jiang, T. Delacy, D. Harrison, and D. Dominey-Howes. 2012. Climate Change Adaptation in the Pacific Island Tourism Sector: Analysing the Policy Environment in Vanuatu. Current Issues in Tourism 15(3):247–274. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Knox, J., T. Hess, A. Daccache, and T. Wheeler. 2012. Climate Change Impacts on Crop Productivity in Africa and South Asia. Environmental Research Letters 7:1–8. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kolstad, E., and K. A. Johansson. 2011. Uncertainties Associated with Quantifying Climate Change Impacts on Human Health: A Case Study for Diarrhea. Environmental Health Perspectives 119(3):299–305. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kraft, N. J. B., M. R. Metz, R. S. Condit, and J. Chave. 2010. The Relationship between Wood Density and Mortality in a Global Tropical Forest Data Set. New Phytologist 188(4):1124–1136. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lal, P., J. Alavalapati, and E. Mercer. 2011. Socio-economic Impacts of Climate Change on Rural United States. Mitigation and Adaptation Strategies for Global Change (7):1381–2386. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lancelot, R., S de La Rocque and V. Chevalier. 2008. Bluetongue and Rift Valley Fever in Livestock: A Climate Change Perspective with a Special Reference to Europe, the Middle East and Africa. In Livestock and Global Climate Change. Proceedings of the BSAS Conference 87. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Larsen, P., S. Goldsmith, O. Smith, M. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor. 2008. Estimating Future Costs for Alaska Public Infrastructure at Risk from Climate Change. Global Environmental Change 18(3):442–457. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Last, P., W. White, D. Gledhill, A. Hobday, R. Brown, G. Edgar, and G. Pecl. 2011. Long Term Shifts in Abundance and Distribution of a Temperate Fish Fauna: A Response to Climate Change and Fishing Practices. Global Ecology and Biogeography 20:58–72. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lerner, A. M., and H. Eakin. 2010. An Obsolete Dichotomy? Rethinking the Rural-Urban Interface in Terms of Food Security and Production in the Global South. Geographical Journal 177(4):311–320. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Lioubimtseva, E., and G. M. Henebry. 2009. Climate and Environmental Change in Arid Central Asia: Impacts, Vulnerability, and Adaptations. Journal of Arid Environments 73(11):963–977. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lobell, D. B., and C. B. Field. 2011. California Perennial Crops in a Changing Climate. Climatic Change 109:317–333. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lobell, D. B., M. Bänziger, C. Magorokosho, and B. Vivek. 2011. Nonlinear Heat Effects on African Maize as Evidenced by Historical Yield Trials. Nature Climate Change 1(1):42–45. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lobell, D. B., M. B. Burke, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon, and R. L. Naylor. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. Science 319:607–610. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lobell, D. B., A. Sibley, and J. I. Ortiz-Monasterio. 2012. Extreme Heat Effects on Wheat Senescence in India. Nature Climate Change 2(3):186–189. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lotze-Campen, H., A. Popp, T. Beringer, C. Müller, A. Bondeau, S. Rost, and W. Lucht. 2010. Scenarios of Global Bioenergy Production: The Trade-offs between Agricultural Expansion, Intensification and Trade. Ecological Modelling 221(18):2188–2196. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** MacDonald, A., R. Calow, D. MacDonald, W. G. Darling, and B. E. O. Dochartaigh. 2009. What Impact Will Climate Change Have on Rural Groundwater Supplies in Africa? Hydrological Sciences Journal 54(4):690–703. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Marshall, B. E. 2012. Does Climate Change Really Explain Changes in the Fisheries Productivity of Lake Kariba (Zambia-Zimbabwe)? Transactions of the Royal Society of South Africa 67:45–51. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McDowell, N. G., D. J. Beerling, D. D. Breshears, R. A. Fisher, K. F. Raffa, and M. Stitt. 2011. The Interdependence of Mechanisms Underlying Climate-driven Vegetation Mortality. Trends in Ecology & Evolution 26(10):523–532. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Michaelian, M., E. H. Hogg, R. J. Hall, and E. Arsenault. 2011. Massive Mortality of Aspen Following Severe Drought along the Southern Edge of the Canadian Boreal Forest. Global Change Biology 17(6):2084–2094. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Moriondo, M., C. Giannakopoulos, and M. Bindi. 2011. Climate Change Impact Assessment: The Role of Climate Extremes in Crop Yield Simulation. Climatic Change 104:679–701. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Morton, J. F. 2007. The Impact of Climate Change on Smallholder and Subsistence Agriculture. Proceedings of the National Academy of Sciences of the United States of America 104(50):19680–19685. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Munday, P. L., G. P. Jones, M. S. Pratchett, and A. J. William. 2008. Climate Change and the Future for Coral Reef Fishes Fish and Fisheries. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** National Research Council (NRC). 2008. Potential Impacts of Climate Change on U.S. Transportation. Transportation Research Board (TRB) Special Report 290. Transportation Research Board. Washington DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ndebele-Murisa, M. R., E. Mashonjowa, and T. Hill. 2011. The Implications of a Changing Climate on the Kapenta Fish Stocks of Lake Kariba, Zimbabwe. Transactions of the Royal Society of South Africa 66(2):105–119. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Nelson, G., A. Palazzo, C. Ringler, T. Sulser, and M. Batka. 2009. The Role of International Trade in Climate Change Adaptation. In: ICTSD–IPC Platform on Climate Change, Agriculture and Trade. Issue Paper no.4. International Centre for Trade and Sustainable Development and International Food & Agricultural Trade Policy Council. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nelson, G. C., H. Valin, R. D. Sands, P. Havlik, H. Ahammad, D. Deryng, J. Elliott, S. Fujimori, E. Heyhoe, P. Kyle, M. von Lampe, H. Lotze-Campen, D. Mason d'Croz, H. van Meijl, D. van der Mensbrugghe, C. Müller, A. Popp, R. Robertson, S. Robinson, E. Schmid, C. Schmitz, A. Tabeau, and D. Willenbockel. 2013. Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks. Proceedings of the National Academy of Sciences of the United States of America (PNAS) 111(9):3274–3279. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nelson, G. C., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. B. Sulser, C. Ringler, S. Msangi, and L. You. 2010. Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options. IFPRI Research Monograph. Washington DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nielsen, J. Ø., S. D'haen, and A. Reenberg. 2012. Adaptation to Climate Change as a Development Project: A Case Study from Northern Burkina Faso. Climate and Development 4(1):16–25. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nyaupane, G., and N. Chhetri. 2009. Vulnerability to Climate Change of Nature-based Tourism in the Nepalese Himalayas. Tourism Geographies 11(1):95–119. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nyaupane, G. P., and S. Poudel. 2011. Linkages among Biodiversity, Livelihood, and Tourism. Annals of Tourism Research 38(4):1344–1366. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** O'Reilly, C. M., S. R. Alin, P. D. Plisnier, A. S. Cohen, and B. A. McKee. 2003. Climate Change Decreases Aquatic Ecosystem Productivity of Lake Tanganyika, Africa. Nature 424:766–768. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ogden, N. H., C. Bounchard, K. Kurtenbach, G. Margos, L. R. Lindsay, L. Trudel, S. Nguon, and F. Milord. 2010. Active and Passive Surveillance and Phylogenetic Analysis of Borrelia burgdorferi Elucidate the Process of Lyme Disease Risk Emergence in Canada. Environmental Health Perspectives 118(7):909–914. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Omumbo, J., B. Lyon, S. Waweru, S. Connor, and M. Thomson. 2011. Raised Temperatures over the Kericho Tea Estates: Revisiting the Climate in the East African Highlands Malaria Debate. Malaria Journal 10:12. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Orlove, B. 2009. The Past, Present and Some Possible Futures of Adaptation. In: Adapting to Climate Change: Thresholds, Values, Governance. First Edition. New York, NY: Cambridge University Press. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ostro, B., S. Rauch, R. Green, B. Malig, and R. Basu. 2010. The Effects of Temperature and Use of Air Conditioning on Hospitalizations. American Journal of Epidemiology 172(9):1053–1061. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Paavola, J. 2008. Livelihoods, Vulnerability and Adaptation to Climate Change in Morogoro, Tanzania. Environmental Science & Policy 11(7):642–654. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Pan, Y., R. Birdsey, J. Fang, R. Houghton, P. Kauppi, W. A. Kurz, O. L. Phillips, A. Shvidenko, S. L. Lewis, J. G. Canadell, P. Ciais, R. B. Jackson, S. Pacala, A. D. McGuire, S. Piao, A. Rautiainen, S. Sitch, and D. Hayes. 2011. A Large and Persistent Carbon Sink in the World's Forests. Science 333(6045):988–993. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Pascual, M., J. A. Ahumada, L. F. Chaves, X. Rodo, and M. Bouma. 2006. Malaria Resurgence in the East African Highlands: Temperature Trends Revisited. Proceedings of the National Academy of Sciences 103(15):5829–5834. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Payet, R., and W. Agricole. 2006. Climate Change in the Seychelles: Implications for Water and Coral Reefs. Ambio 35(4):182–189. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Peng, C., Z. Ma, X. Lei, Q. Zhu, H. Chen, W. Wang, S. Liu, W. Li, X. Fang, and X. Zhou. 2011. A Drought Induced Pervasive Increase in Tree Mortality across Canada's Boreal Forests. Nature Climate Change 1(9):467–471. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Perry, A. L., P. J. Low, J. R. Ellis, and J. D. Reynolds. 2005. Climate Change and Distribution Shifts in Marine Fishes. Science 308:1912–1915. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Phillips, O.L., G. van der Heijden, S. L. Lewis, G. Lopez-Gonzalez, L. E. O. C. Aragao, J. Lloyd, Y. Malhi, A. Monteagudo, A. Almeida, E. Alvarez Davila, I. Amaral, S. Andelman, A. Andrade, L. Arroyo, G. Aymard, T. R. Baker, L. Blanc, D. Bonal, A. C. Alves de Oliveira, K.-J. Chao, N. Davila Cardozo, L. da Costa, T. R. Feldpausch, J. B. Fisher, N. M. Fyllas, M. A. Freitas, D. Galbraith, E. Gloor, N. Higuchi, E. Honorio, E. Jimenez, H. Keeling, T. J. Killeen, J. C. Lovett, P. Meir, C. Mendoza, A. Morel, P. Nunez Vargas, S. Patino, K. S. H. Peh, A. Pena Cruz, A. Prieto, C. A. Quesada, F. Ramirez, H. Ramirez, A. Rudas, R. Salamao, M. Schwarz, J. Silva, M. Silveira, J. W. F. Slik, B. Sonke, A. S. Thomas, J. Stropp, J. R. D. Taplin, R. Vasquez, E. and Vilanova. 2010. Drought-mortality Relationships for Tropical Forests. New Phytologist 187(3):631–646. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Pielke, R. A., A. Pitman, D. Niyogi, R. Mahmood, C. McAlpine, F. Hossain, K. K. Goldewijk, U. Nair, R. Betts, S. Fall, M. Reichstein, P. Kabat, and N. de Noblet. 2011. Land Use/Land Cover Changes and Climate: Modeling Analysis and Observational Evidence. Wiley Interdisciplinary Reviews – Climate Change 2(6):828–850. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Pinto, H. S., J. J. Zullo, E. D. Assad, and B. A. Evangelista. 2007. O Aquecimento Global e a Cafeicultura. Boletim Da Sociedade Brasileira De Meteorologia 30:65–72. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Polvani, L. M., D. W. Waugh, G. J. P. Correa, and S. W. Son. 2011. Stratospheric Ozone Depletion: The Main Driver of Twentieth-Century Atmospheric Circulation Changes in the Southern Hemisphere. Journal of Climate 24(3):795–812. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Potter, R. B. 2000. The Urban Caribbean in an Era of Global Change. First Edition. Brookfield, CT. Ashgate Publishing Ltd. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Rao, K. P. C., W. G. Ndegwa, K. Kizito, and A. Oyoo. 2011. Climate Variability and Change: Farmer Perceptions and Understanding of Intra-seasonal Variability in Rainfall and Associated Risk in Semi-arid Kenya. Experimental Agriculture 47(2):267–291. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Renaudeau, D., J. Gourdine and N. St-Pierre. 2011. A Meta-analysis of the Effects of High Ambient Temperature on Growth Performance of Growing-Finishing Pigs. Journal of Animal Science 89:2220–2230. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Sahu, S., M. Sett, and T. Kjellstrom. 2013. Heat Exposure, Cardiovascular Stress and Work Productivity in Rice Harvesters in India: Implications for a Climate Change Future. Industrial Health 51(4):424–431. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Sarvala, J., V. T. Langenberg, K. Salonen, D. Chitamwebwa, G. W. Coulter, T. Huttula, R. Kanyaru, P. Kotilainen, S. Makasa, N. Mulimbwa, and H. Molsa. 2006. Fish Catches from Lake Tanganyika Mainly Reflect Changes in Fishery Practices, not Climate. Verhandlungen Internationale Vereinigung Für Theoretische Und Angewandte Limnologie 29:1182–1188. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Schmitz, C., A. Biewald, H. Lotze-Campen, A. Popp, J. P. Dietrich, B. Bodirsky, M. Krause, and I. Weindl. 2012. Trading More Food: Implications for Land Use, Greenhouse Gas Emissions, and the Food System. Global Environmental Change 22(1):189–209. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Scott, D., B. Jones, and J. Konopek. 2007. Implications of Climate and Environmental Change for Nature-based Tourism in the Canadian Rocky Mountains: A Case Study of Waterton Lakes National Park. Tourism Management 28(2):570–579. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Seo, S. N., and R. Mendelsohn. 2007a. Climate Change Adaptation in Africa: A Microeconomic Analysis of Livestock Choice. In: World Bank Policy Research Working Paper 4277. World Bank. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Seo, S. N., and R. Mendelsohn. 2007b. The Impact of Climate Change on Livestock Management in Africa: A Structural Ricardian Analysis. In: Policy Research Working Paper 4603. World Bank. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Smith, L., H. Alderman, and D. Aduayom. 2006. Food Insecurity in Sub-Saharan Africa: New Estimates from Household Expenditure Survey. IFPRI Research Report no. 146. IFPRI. Washington DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Stern, D. I., P. W. Gething, C. W. Kabaria, W. H. Temperley, A. M. Noor, E. A. Okiro, G. D. Shanks, R. W. Snow, and S. I. Hay. 2011. Temperature and Malaria Trends in Highland East Africa. PLoS One 6(9):e24524. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tamiotti, L., R. Teh, V. Kulaçoglu, A. Olhoff, B. Simmons, and H. Abaza. 2009. Trade and Climate Change. World Trade Organization (WTO), United Nations Environment Programme (UNEP). Geneva, Switzerland. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Thuiller, W., O. Broennimann, G. Hughes, M. Alkemade, G. F. Midgley, and F. Corsie. 2006. Vulnerability of African Mammals to Anthropogenic Climate Change under Conservative Land Transformation Assumptions. Global Change Biology. 12(3):424–440. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tsai, D. H., J. L. Wang, C. H. Wang, and C. C. Chan. 2008. A Study of Ground-level Ozone Pollution, Ozone Precursors and Subtropical Meteorological Conditions in Central Taiwan. Journal of Environmental Monitoring 10(1):109–118. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** UN-DESA Population Division. 2013. World Population Prospects: The 2012 Revision, Highlights and Advance Tables. United Nations, Department of Economic and Social Affairs, Population Division Working Paper No. ESA/P/WP.228. United Nations, Department of Economic and Social Affairs: Population Division (ed.). New York, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Van der Geest, K. 2011. North–South Migration in Ghana: What Role for the Environment? International Migration 49(S1):e69–e94. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** van der Leun, J. C., R. D. Piacentini, and F. R. de Gruijl. 2008. Climate Change and Human Skin Cancer. Photochemical & Photobiological Sciences 7(6):730–733. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fule, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, and T. T. Veblen. 2009. Widespread Increase of Tree Mortality Rates in the Western United States. Science 323(5913):521–524. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Verburg, R., E. Stehfest, G. Woltjer, and B. Eickhout. 2009. The Effect of Agricultural Trade Liberalisation on Land-use Related Greenhouse Gas. Global Environmental Change 19(4):434–446. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Vermeulen, S. J., B. Campbell, and J. Ingram. 2012. Climate Change and Food Systems. Annual Review of Environment and Resources 37:195–222. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Vincent, K., T. Cull, D. Chanika, P. Hamazakaza, A. Joubert, E. Macome, and C. Mutonhodza-Davies. 2013. Farmers' Responses to Climate Variability and Change in Southern Africa: Is it Coping or Adaptation. Climate and Development 5(3):194–205. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wang, R., Z. Qiang, H. Liu, Q. Yang, H. Zhao, and Z. Wan. 2007. Impact of Climate Warming on Cotton Growth in the Hexi Corridor Area. Advances in Climate Change Research 3(1):57–59. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Watkiss, P., T. E. Downing, and J. Dyszynski. 2010. ADAPT Cost Project: Analysis of the Economic Costs of Climate Change Adaptation in Africa. Nairob, Kenya. United Nations Environment Programme (UNEP). Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Weaver, C., X. Liang, J. Zhu, P. Adams, P. Amar, J. Avise, M. Caughey, J. Chen, R. Cohen, and E. Cooter. 2009. A Preliminary Synthesis of Modeled Climate Change Impacts on US Regional Ozone Concentrations. Bulletin of the American Meteorological Society 90(12):1843–1863. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wellard, K., D. Kambewa, and S. Snapp. 2012. Climate Change and Threatened Communities: Vulnerability, Capacity and Action. First Edition. Practical Action Publications. Rugby, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wilkinson, P., K. R. Smith, S. Beevers, C. Tonne, and T. Oreszczyn. 2007. Energy, Energy Efficiency, and the Built Environment. The Lancet 370(9593):1175–1187. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wolfsegger, C., S. Gossling, and D. Scott. 2008. Climate Change Risk Appraisal in the Austrian Ski Industry. Tourism Review International 12(1):13–23. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wong, T., and R. Brown. 2009. The Water Sensitive City: Principles for Practice. Water Science and Technology 60(3):673–682. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** World Bank. 2008. Reshaping Economic Geography: World Development Report 2009. World Bank. Washington DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** World Bank. 2010. Economics of Adaptation to Climate Change: Synthesis Report. Washington, DC, World Bank. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Zimmerman, R., and C. Faris. 2010. Chapter 4: Infrastructure Impacts and Adaptation Challenges. Annals of the New York Academy of Sciences 1196(1):63–86. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Brückner, M., and A. Ciccone. 2010. International Commodity Prices, Growth and the Outbreak of Civil War in Sub-Saharan Africa. Economic Journal 120(544):519–534. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cameron, E. S. 2012. Securing Indigenous Politics: A Critique of the Vulnerability and Adaptation Approach to the Human Dimensions of Climate Change in the Canadian Arctic. Global Environmental Change 22(1):103–114. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Carter, M., P. Little, T. Mogues, and W. Negatu. 2007. Poverty Traps and Natural Disasters in Ethiopia and Honduras. World Development 35(5):835–856. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Crate, S. A. 2008. Gone the Bull of Winter? Grappling with the Cultural Implications of and Anthropology's Role(s) in Global Climate Change. Current Anthropology 49(4):569–595. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Crate, S. A., and M. Nuttall (eds.). 2009. Anthropology and Climate Change: From Encounters to Actions. Left Coast Press. Walnut Creek, CA. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cunsolo-Willox, A., S. L. Harper, J. D. Ford, K. Landman, K. Houle, and V. L. Edge. The Rigolet Inuit Community Government. 2012. From this Place and of this Place: Climate Change, Sense of Place, and Health in Nunatsiavut, Canada. Social Science & Medicine 75(3):538–547. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Cunsolo-Willox, A., S. L. Harper, V. L. Edge, K. Landman, K. Houle, and J. D. Ford. The Rigolet Inuit Community Government. 2013. The Land Enriches the Soul: On Climatic and Environmental Change, Affect, and Emotional health and Well-being in Rigolet, Nunatsiavut, Canada. Emotion, Space and Society 6:14–24. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Dixon, J. 2009. What Causes Civil Wars? Integrating Quantitative Research Findings. International Studies Review 11(4):707–735. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Doherty, T. J., and S. Clayton. 2011. The Psychological Impacts of Global Climate Change. American Psychologist 66 (4):265–276. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Eboli, F., R. Parrado, and R. Roson. 2010. Climate-change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Model. Environment and Development Economics 15(5):515–533. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Eira, I. M. G., C. Jaedicke, O. H. Magga, N. G. Maynard, D. Vikhamar-Schuler, and S. D. Mathiesen. 2013. Traditional Sámi Snow Terminology and Physical Snow Classification—Two Ways of Knowing. Cold Regions Science and Technology 85:117–130. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ellemor, H. 2005. Reconsidering Emergency Management and Indigenous Communities in Australia. Environmental Hazards 6(1):1–7. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Elliott, J. R., and J. Pais. 2006. Race, Class, and Hurricane Katrina: Social Differences in Human Responses to Disaster. Social Science Research 35(2):295–321. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Falk, W. W., M. O. Hunt, and L. L. Hunt. 2006. Hurricane Katrina and New Orleanians' Sense of Place. Du Bois Review 3(1):115–128. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Feng, S., A. B. Krueger, and M. Oppenheimer. 2009. Linkages among Climate Change, Crop Yields and Mexico–US Cross-border Migration. Proceedings of the National Academy of Sciences 107(32):14257–14262. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Fernández-Giménez, M. E., B. Batkhishig, and B. Batbuyan. 2012. Cross-boundary and Cross-level Dynamics Increase Vulnerability to Severe Winter Disasters (dzud) in Mongolia. Global Environmental Change 22(4):836–851. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Findley, S. E. 1994. Does Drought Increase Migration? A Study of Migration from Rural Mali during the 1983–1985 Drought. International Migration Review 28(3):539–553. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Finucane, M. L. 2009. Why Science Alone Won't Solve the Climate Crisis: Managing Climate Risks in the Pacific. Asia Pacific Issues 89:1–8. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Flint, C. G., E. S. Robinson, J. Kellogg, G. Ferguson, L. BouFajreldin, M. Dolan, I. Raskin, and M. A. Lila. 2011. Promoting Wellness in Alaskan Villages: Integrating Traditional Knowledge and Science of Wild Berries. Ecohealth 8(2):1–11. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Forbes, B. C. 2007. Equity, Vulnerability and Resilience in Social–

Ecological Systems: A Contemporary Example from the Russian Arctic. In: Equity and the Environment. Elsevier, Oxford. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ford, J. D., T. Pearce, J. Gilligan, B. Smit, and J. Oakes. 2008. Climate Change and Hazards Associated with Ice Use in Northern Canada. Arctic, Antarctic, and Alpine Research 40(4):647–659. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ford, J. D., W. Gough, G. Laidler, J. MacDonald, C. Irngaut, and K. Qrunnut. 2009. Sea Ice, Climate Change, and Community Vulnerability in Northern Foxe Basin, Canada. Climate Research 38(2):137–154. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Foresight. 2011. Migration and Global Environmental Change. UK Government Office for Science. London, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Frazier, T. G., N. Wood, and B. Yarnal. 2010. Stakeholder Perspectives on Land-use Strategies for Adapting to Climate-Change-Enhanced Coastal Hazards: Sarasota, Florida. Applied Geography 30(4):506–517. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gaurav, K., R. Sinha, and P. Panda. 2011. The Indus Flood of 2010 in Pakistan: A Perspective Analysis Using Remote Sensing Data. Natural Hazards 59(3):1815–1826. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gleditsch, N. P. 2012. Whither the Weather? Climate Change and Conflict. Journal of Peace Research 49(1):3–9. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Green, D., L. Alexander, K. McInnes, J. Church, N. Nicholls, and N. White. 2010. An Assessment of Climate Change Impacts and Adaptation for the Torres Strait Islands, Australia. Climatic Change 102(3–4):405–433. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Gregory, R., and W. Trousdale. 2009. Compensating Aboriginal Cultural Losses: An Alternative Approach to Assessing Environmental Damages. Journal of Environmental Management 90(8):2469–2479. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hall, J. W., E. P. Evans, E. C. Penning-Rosell, P. B. Sayers, C. R. Thorne, and A. J. Saul. 2003. Quantified Scenarios Analysis of Drivers and Impacts of Changing Flood Risk in England and Wales: 2030–2100. Environmental Hazards 5(3–4):51–65. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hallegatte, S. 2012. A Framework to Investigate the Economic Growth Impact of Sea Level Rise. Environmental Research Letters 7(1):015604–015611. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Haug, R. 2002. Forced Migration, Processes of Return and Livelihood Construction among Pastoralists in Northern Sudan. Disasters 26(1):70–84. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hegre, H., and N. Sambanis. 2006. Sensitivity Analysis of Empirical Results on Civil War Onset. Journal of Conflict Resolution 50(4):508–535. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Henry, S., B. Schoumaker, and C. Beauchemin. 2004. The Impact of Rainfall on the First Out-migration: A Multilevel Event-History Analysis in Burkina Faso. Population and Environment 25(5):423–460. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hitchcock, R. K. 2009. From Local to Global: Perceptions and Realities of Environmental Change among Kalahari San. In: Anthropology and Climate Change: From Encounters to Actions. Left Coast Press. Walnut Creek, CA. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hori, M., and M. J. Schafer. 2010. Social Costs of Displacement in

Louisiana after Hurricanes Katrina and Rita. Population and Environment 31(1–3):64–86. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Houghton, K. J., A. T. Vafeidis, B. Neumann, and A. Proelss. 2010. Maritime Boundaries in a Rising Sea. Nature Geoscience 3(12):813–816. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hovelsrud, G, B. Poppel, B. Oort, and J. Reist. 2011. Arctic Societies, Cultures, and Peoples in a Changing Cryosphere. Ambio 40(1):100–110. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Hsiang, S., M. Burke, and E. Miguel. 2013. Quantifying the Influence of Climate on Human Conflict. Science 341. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Jacka, J. 2009. Global Averages, Local Extremes: The Subtleties and Complexities of Climate Change in Papua New Guinea. In: Anthropology and Climate Change: From Encounters to Actions. Left Coast Press. Walnut Creek, CA. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Johnson, C. A. 2012. Governing Climate Displacement: The Ethics and Politics of Human Resettlement. Environmental Politics 21(2):308–328. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kainuma, M., Y. Matsuoka, T. Morita, T. Masui, and K. Takahashi. 2004. Analysis of Global Warming Stabilization Scenarios: The Asian-Pacific Integrated Model. Energy Economics 26(4):709–719. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Kofinas G, the communities of Aklavik, Arctic Village, Old Crow, and McPherson F. 2002. Community Contributions to Ecological Monitoring: Knowledge Co-production in the U.S.-Canada Arctic Borderlands. In: The Earth Is Faster Now: Indigenous Observations of Arctic Environmental Change. Fairbanks, AK. Arctic Research Consortium of the United States. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Koubi, V., T. Bernauer, A. Kalbhenn, and G. Spilker. 2012. Climate Variability, Economic Growth, and Civil Conflict. Journal of Peace Research 49(1):113–127. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Landry, C. E., O. Bin, P. Hindsley, J. C. Whitehead, and K. Wilson. 2007. Going Home: Evacuation-Migration Decisions of Hurricane Katrina Survivors. Southern Economic Journal 74(2):326–343. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Leadley, P. W., H. M. Pereira, R. Alkemade, J. F. Fernandez-Manjarres, V. Proenca, J. P. W. Scharlemann, and M. J. Walpole. 2010. Biodiversity Scenarios: Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services, Secretariat of the Convention on Biological Diversity. Science Technical Series no. 50.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Lilleor, H. B., and K. Van den Broeck. 2011. Drivers of Migration and Climate Change in Less Developed Countries. Global Environmental Change 21(Supp):S70–S81. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Maldonado, J., C. Shearer, R. Bronen, K. Peterson, and H. Lazrus. 2013. The Impact of Climate Change on Tribal Communities in the US: Displacement, Relocation, and Human Rights. Climatic Change. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Marfai, M., L. King, J. Sartohadi, S. Sudrajat, S. Budiani, and F. Yulianto. 2008. The Impact of Tidal Flooding on a Coastal Community in Semarang, Indonesia. The Environmentalist 28(3):237–248. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Marino, E. 2012. The Long History of Environmental Migration: Assessing Vulnerability Construction and Obstacles to Successful Relocation in Shishmaref, Alaska. Global Environmental Change 22(2):374–381. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McLeman, R. 2009. Climate Change and Adaptive Human Migration: Lessons from Rural North America. In: Adapting to Climate Change: Thresholds, Values, Governance.

Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** McNeeley, S. M. 2012. Examining Barriers and Opportunities for Sustainable Adaptation to Climate Change in Interior Alaska. Climatic Change 111(3–4):835–857. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mehrotra, S., C. Rosenzweig, and W. D. Solecki. 2011. Cities, Disaster and Climate Risk. In: Climate Change and Cities. Cambridge University Press, Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mendelsohn, R., A. Dinar, and L. Williams. 2006. The Distributional Impact of Climate Change on Rich and Poor Countries. Environment and Development Economics 11(02):159–178. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mendelsohn, R., W. Morrison, M. E. Schlesinger, and N. G. Andronova. 2000. Country-specific Market Impacts of Climate Change. Climatic Change 45(3):553–569. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Miguel, E., S. Satyanath, and E. Sergenti. 2004. Economic Shocks and Civil Conflict: An Instrumental Variables Approach. Journal of Political Economy 112(4):725–753. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Mortreux, C., and J. Barnett. 2009. Climate Change, Migration and Adaptation in Funafuti, Tuvalu. Global Environmental Change 19(1):105–112. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nakashima D., and M. Rou´e. 2002. Indigenous Knowledge, Peoples and Sustainable Practice. In: Social and Economic Dimensions of Global Environmental Change. John Wiley, Chichester. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nicholls, R. J., N. Marinova, J. A. Lowe, S. Brown, P. Vellinga, D. de Gusmão, J. Hinkel, J., and R. S. J. Tol. 2011. Sea-level Rise and its Possible Impacts Given a 'Beyond

4°C World' in the Twenty-First Century. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369(1934):161–181. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Nuttall, M. 2009. Living in a World of Movement—Human Resilience to Environemntal Instability in Greenland. In: Anthropology and Climate Change: From Encounters to Actions. Left Coast Press. Walnut Creek, CA. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Oberthür, T., E. Barrios, S. Cook, H. Usma, and G. Escobar. 2004. Increasing the Relevance of Scientific Information in Hillside Environments through Understanding of Local Soil Management in a Small Watershed of the Colombian Andes. Soil Use and Management 20(1):23–31. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Oliver-Smith, A. 2011. Sea Level Rise, Local Vulnerability and Involuntary Migration. In: Migration and Climate Change. Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Paul, B. K. 2005. Evidence against Disaster-induced Migration: The 2004 Tornado in North-central Bangladesh. Disasters 29(4):370–385. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Peras, R. J., J. M. Pulhin, R. D. Lasco, R. V. O. Cruz, and F. B. Pulhin. 2008. Climate Variability and Extremes in the Pantabangan-Carranglan Watershed, Philippines: Assessment of Impacts and Adaptation Practices. Journal of Environmental Science and Management 11(2):14–31. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Ravera, F., D. Tarrasón, and E. Simelton. 2011. Envisioning Adaptive Strategies to Change: Participatory Scenarios for Agropastoral Semiarid Systems in Nicaragua. Ecology and Society 16(1). Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Rybråten, S., and G. K. Hovelsrud. 2010. Local Effects of Global Climate Change: Differential Experiences of Sheep Farmers and Reindeer Herders in Unjarga, Nesseby, a Coastal Sámi Community in Northern Norway. In: Community Adaptation and

Vulnerability in Arctic Communities. Springer, Berlin. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Sánchez-Cortés, M., and E. Chavero. 2011. Indigenous Perception of Changes in Climate Variability and its Relationship with Agriculture in a Zoque Community of Chiapas, Mexico. Climatic Change 107(3–4):363–389. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Scheffran, J., M. Brzoska, H. G. Brauch, P. M. Link, and J. Schilling (eds.). 2012. Climate Change, Human Security and Violent Conflict: Challenges for Societal Stability. Springer, Berlin. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Shah, A., and O. G. Sajitha. 2009. Dwindling Forest Resources and Economic Vulnerability among Tribal Communities in a Dry, Sub-humid Region in India. Journal of International Development 21(3):419–432. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Stern, N. 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press. Cambridge, UK. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Strauss, S. 2012. Are Cultures Endangered by Climate Change? Yes, but…. Wiley Interdisciplinary Reviews: Climate Change 3(4):371–377. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Theisen, O., N. P. Gleditsch and H. Buhaug. 2013. Is Climate Change a Driver of Armed Conflict? Climatic Change 117(3):613–625. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tompkins, E. L., L. A. Hurlston, and W. Poortinga. 2009. Foreignness as a Constraint on Learning: The Impact of Migrants on Disaster Resilience in Small Islands. Environmental Hazards 8(4):263–277. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Turner, N. J., and H. Clifton. 2009. It's So Different Today: Climate Change and Indigenous Lifeways in British Columbia, Canada. Global Environmental Change 19(2):180–190. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Tyler, N. J. C., J. M. Turi, M. A. Sundset, K. S. Bull, M. N. Sara, E. Reinert, N. Oskal, C. Nellemann, J. J. McCarthy, S. D. Mathiesen, M. L. Martello, O. H. Magga, G. K. Hovelsrud, I. Hanssen-Bauer, N. I. Eira, I. M. G. Eira, and R. W. Corell. 2007. Saami Reindeer Pastoralism under Climate Change: Applying a Generalized Framework for Vulnerability Studies to a Sub-arctic Social-Ecological System. Global Environmental Change 17(2):191–206. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** United Nations Development Programme (UNDP). 2007. Human Development Report 2007/2008: Fighting Climate Change: Human Solidarity in a Divided World. Palgrave Macmillan. New York, NY. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Vogel, C., S. C. Moser, R. E. Kasperson, and G. D. Dabelko. 2007. Linking Vulnerability, Adaptation, and Resilience Science to Practice: Pathways, Players, and Partnerships. Global Environmental Change 17(3–4):349–364. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wang, M. Z., M. Amati, and F. Thomalla. 2012. Understanding the Vulnerability of Migrants in Shanghai to Typhoons. Natural Hazards 60(3):1189–1210. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Warner, K., and T. Afifi. 2013. Where the Rain Falls: Evidence from 8 Countries: How Households Use Content and Erosive Migration to Manage the Risk of Rainfall Variability and Food Insecurity. Climate and Development 6(1):1–17. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Weede, E. 2004. On Political Violence and its Avoidance. Acta Politica 39(2):152–178. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change **citing** Wenzel, G. W. 2009. Canadian Inuit Subsistence and Ecological Instability—If the Climate Changes, Must the Inuit? Polar Research 28(1):89–99. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** West, C. T., C. Roncoli, and F. Ouattara. 2008. Local Perceptions and Regional Climate Trends on the Central Plateau of Burkina Faso. Land Degradation and Development 19(3):289–304. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Wittrock, V., S. N. Kulshreshtha, and E. Wheaton. 2011. Canadian Prairie Rural Communities: Their Vulnerabilities and Adaptive Capacities to Drought. Mitigation and Adaptation Strategies for Global Change 16(3):267–290. Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** World Bank. 2010. World Development Report 2010: Development and Climate Change. World Bank. Washington, DC, Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change **citing** Correa, M.d.P., S. Godin-Beekmann, M. Haeffelin, S. Bekki, P. Saiag, J. Badosa, F. Jegou, A. Pazmino, and E. Mahe. 2013. Projected Changes in Clear-sky Erythemal and Vitamin D Effective UV Doses for Europe over the Period 2006 to 2100. Photochemical & Photobiological Sciences 12(6):1053–1064.). Cambridge, UK and New York, NY, Cambridge University Press.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY **citing** Barry, J. P., S. Widdicombe, and J. Hall-Spencer. 2011: Effects of Ocean Acidification on Marine Biodiversity and Ecosystem Function. In: Ocean Acidification [Gattuso, J.-P., and L. Hansson (eds.)]. Oxford University Press, Oxford, UK, pgs. 192–209.

IPCC. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V. R., C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 688 pp.

IPCC. 2014b. Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth

Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY.

IPCC. 2014c. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK and New York, NY.

IPCS (International Programme on Chemical Safety). 2002. Concise International Chemical Assessment Document 40. Formaldehyde. World Health Organization.

IPEEC (International Partnership for Energy Efficiency Cooperation). 2014. Japan's Fuel Economy. June 11, 2014.

Irons, R. D., W. S. Stillman, D. B. Colagiovanni, and V. A. Henry. 1992. Synergistic Action of the Benzene Metabolite Hydroquinone on Myelopoietic Stimulating Activity of Granulocyte/Macrophage Colony-Stimulating Factor in Vitro. *Proceedings of the National Academy of Sciences of the United States of America* 89(9):3691–3695.

ISO (International Organization for Standardization). 2006. Environmental Management—Life Cycle Assessment—Requirements and Guidelines. International Organization for Standardization. ISO/FDIS 14044.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Bernhardt, E. S., J. J. Barber, J. S. Pippen, L. Taneva, J. A. Andrews, and W. H. Schlesinger. 2006. Long-Term Effects of Free Air CO_2 Enrichment (FACE) on Soil Respiration. *Biogeochemistry* 77:91–116. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Canadell, J. G., L. F. Pitelka, and J. S. I. Ingram. 1995. The Effects of Elevated [CO_2] on Plant-Soil Carbon Below-Ground: A Summary and Synthesis. Plant Soil 187:391–400. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Finzi, A.C., R.J. Norby, C. Calfapietra, A. Gallet-Budynek, B. Gielen, W. E. Holmes, M. R. Hoosbeek, C.M. Iversen, R. B. Jackson, M. E. Kubiske, J. Ledford, M. Liberloo, R. Oren, A. Polle, S. Pritchard, D. R. Zak, W. H. Schlesinger, and R. Ceulemans. 2007. Increases in Nitrogen Uptake Rather than Nitrogen-Use Efficiency Support Higher Rates of Temperate Forest Productivity under Elevated CO_2. Proceedings of the National Academy of Sciences 104:14014–14019. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Fitter, A. H., G. K. Self, J. Wolfenden, M. M. I. van Vuuren, T. K. Brown, L. Williamson, J. D. Graves, and D. Robinson. 1995. Root Production and Mortality under Elevated Atmospheric Carbon Dioxide. Plant and Soil 187:299–306. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Gill, R.

A., L. J. Anderson, H. W. Polley, H. B. Johnson, and R. B. Jackson. 2006. Potential Nitrogen Constraints on Soil Carbon Sequestration under Low and Elevated Atmospheric CO_2. *Ecology* 87:41–52. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Hoosbeek, M. R., J. M. Vos, M. B. J. Meinders, E. J. Velthorst, and G. E. Scarascia-Mugnozza. 2007. Free Atmospheric CO_2 Enrichment (FACE) Increased Respiration and Humification in the Mineral Soil of a Poplar Plantation. Geoderma 138:204–212. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Hungate, B. A., E. A. Holland, R. B. Jackson, F. S. Chapin, III, H. A. Mooney, and C. B. Field. 1997. On the Fate of Carbon in Grasslands under Carbon Dioxide Enrichment. Nature 388:576–579. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Karberg, N. J., K. S. Pregitzer, J. S. King, A. L. Friend, and J. R. Wood. 2005. Soil Carbon Dioxide Partial Pressure and Dissolved Inorganic Carbonate Chemistry under Elevated Carbon Dioxide and Ozone. Oecologia 142:296–306. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** King, J. S., K. S. Pregitzer, D. R. Zak, J. Sober, J. G. Isebrands, R. E. Dickson, G. R. Hendrey, and D. F. Karnosky. 2001. Fine-Root Biomass and Fluxes of Soil Carbon in Young Stands of Paper Birch and Trembling Aspen as Affected by Elevated Atmospheric CO_2 and Tropospheric O_3. Oecologia 128:237–250. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Luo, Y., R. B. Jackson, C. B. Field, and H. A. Mooney. 1996. Elevated CO_2 Increases Belowground Respiration in California Grasslands. Oecologia 108:130–137. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Matamala, R., and W. H. Schlesinger. 2000. Effects of Elevated Atmospheric CO2 on Fine Root Production and Activity in an Intact Temperate Forest Ecosystem. *Global Change Biology* 6:967–979. Ecology 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Norby, R. J., J. Ledford, C. D. Reilly, N. E. Miller, and E. G. O'Neill. 2004. Fine-Root Production Dominates Response of a Deciduous Forest to Atmospheric CO_2 Enrichment. Proceedings of the National Academy of Sciences 101:9689–9693. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Pendall, E., S. W. Leavitt, T. Brooks, B. A. Kimball, P. J. Pinter, G. W. Wall, R. L. LaMorte, G. Wechsung, F.

Wechsung, F. Adamsen, A. D. Matthias, and T. L. Thompson. 2001. Elevated CO_2 Stimulates Soil Respiration in a FACE Wheat Field. Basic and Applied Ecology 2:193–201. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Sposito, G. 1989. The Chemistry of Soils. Oxford University Press: New York, NY. *Ecology* 90(12):3352–3366.

Jackson, R. B., C. W. Cook, J. S. Pippen, and S. M. Palmer. 2009. Increased Belowground Biomass and Soil CO_2 Fluxes after a Decade of Carbon Dioxide Enrichment in a Warm-Temperate Forest **citing** Wan, S., R. J. Norby, J. Ledford, and J. F. Weltzin. 2007. Responses of Soil Respiration to Elevated CO_2, Air Warming, and Changing Soil Water Availability in a Model Old-Field Grassland. Global Change Biology 13:2411–2424. *Ecology* 90(12):3352–3366.

Jackson, R. B., A. Down, N. G. Phillips, R. C. Ackley, C. W. Cook, D. L. Plata, and K. Zhao. 2014. Natural Gas Pipeline Leaks across Washington, DC. *Environmental Science & Technology* 48(3):2051–2058.

Jacobson, G. L., I. J. Fernandez, P. A. Mayewski, and C. V. Schmitt (eds.). 2009. Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. *Available at*: http://www.climatechange.umaine.edu/mainesclimatefuture/. (Accessed: June 18, 2012) **citing** Kingston, D., G. McGregor, D. Hannah, and D. Lawler. 2007. Large-scale Climate Controls on New England River Flow. *Journal of Hydrometeorology* 8:367–379.

Jacobson, M. Z. 2010. Short-term Effects of Controlling Fossil-fuel Soot, Biofuel Soot and Gases, and Methane on Climate, Arctic Ice, and Air Pollution Health. *Journal of Geophysical Research: Atmospheres* (1984–2012) 115(D14):209.

Jacques, J.-M. S., S. Lapp, Y. Zhao, E. M. Barrow, and D. J. Sauchyn. 2013. Projected Northern Rocky Mountain Annual Streamflow for 2000–2099 under the B1, A1B and A2 SRES Emissions Scenarios. Quaternary International 310 (Complete).

Jain, S., Chen, H., and J. Schwank. 2006. Techno-Economic Analysis of Fuel Cell Auxiliary Power Units as Alternatives to Idling. *Journal of Power Sources* 160:474–484.

Janssen, E., D. J. Wuebbles, K. E. Kunkel, S. C. Olsen, and A. Goodman. 2014. Observational-and Model-based Trends and Projections of Extreme Precipitation over the Contiguous United States. *Earth's Future* 2(2):99–113.

Jerrett, M., R. T. Burnett, P. Kanaroglou, J. Eyles, N. Finkelstein, C. Giovis, and J. R. Brook. 2001. A GIS-Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada. *Environment and Planning A* 33(6):955–974.

Jiang, M., H. Wu, K. Tang, M. Kim, S. Senthooran, H. Friz, and Y. Zhang. 2011. Evaluation and Optimization of Aerodynamic and Aero-Acoustic Performance of a Heavy Truck using Digital Simulation. SAE Technical Paper, SEA International.

Johnson, W. C., B. V. Millett, T. Gilmanov, R. A. Voldseth, G. R. Gunttenspergen, and D. E. Naugle. 2005. Vulnerability of Northern Prairie Wetlands to Climate Change. *BioScience* 55(10):863–872.

Johnston, P. Undated. New Technologies—Tires. Michelin North America, Greenville, SC. *Available at*: http://highwaytransport.transportation.org/Documents/Johnston.ppt. (Accessed: July 16, 2014).

Jones, B. M., C. D. Arp, K. M. Hinkel, R. A. Beck, J. A. Schmutz, and B. Winston. 2009. Arctic Lake Physical Processes and Regimes with Implications for Winter Water Availability and Management in the National Petroleum Reserve Alaska. *Environmental Management* 43(6):1071–1084.

Jongman, B., P. J. Ward, and J. C. J. H. Aerts. 2012. Global Exposure to River and Coastal Flooding: Long Term Trends and Changes. Global Environmental Change-Human and Policy Dimensions 22(4):823–835. Cambridge, UK and New York, NY, Cambridge University Press.

Joughin, I., B. E. Smith, and B. Medley. 2014. Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica. *Science* 344(6185):735–738.

Justic, D., N. N. Rabalais, and R. E. Turner. 1996. Effects of Climate Change on Hypoxia in Coastal Waters: A Doubled CO_2 Scenario for the Northern Gulf of Mexico. *Limnology and Oceanography* 41:992–1003.

Kaierle, S., M. Dahmen, and O. Gudukkurt. 2011. Eco-Efficiency of Laser Welding Applications. SPIE Eco-Photonics 8065.

Kammerbauer, H., H. Selinger, R. Römmelt, A. Ziegler-Jöhns, D. Knoppik, and B. Hock. 1987. Toxic Components of Motor Vehicle Emissions for the Spruce Picea abies. *Environmental Pollution* 48(3):235–243.

Kan, H., G. Heiss, K. M. Rose, E. A. Whitsel, F. Lurmann, and S. J. London. 2008. Prospective Analysis of Traffic Exposure as a Risk Factor for Incident Coronary Heart Disease: the Atherosclerosis Risk in Communities (ARIC) Study. *Environental Health Perspectives* 116(11):1463–1468. doi:10.1289/ehp.11290.

Karvetski, C. W., J. H. Lambert, J. M. Keisler, B. Sexauer, and I. Linkov. 2011. Climate Change Scenarios: Risk and Impact Analysis for Alaska Coastal Infrastructure. *International Journal of Risk Assessment and Management* 15(23):258–274.

Kaushal, S. S., G. E. Likens, N. A. Jaworski, M. L. Pace, A. M. Sides, D. Seekell, K. T. Belt, D. H. Secor, and R. L. Wingate. 2010. Rising Stream and River Temperatures in the United States. *Frontiers in Ecology and the Environment* 8(9):461–466.

Keener, V.W., K. Hamilton, S.K. Izuka, K.E. Kunkel, L.E. Stevens, and L. Sun. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 8. Climate of the Pacific Islands, NOAA Technical Report NESDIS 142-8.

Kelly, A. E., and M. L. Goulden. 2008. Rapid Shifts in Plant Distribution with Recent Climate Change. *Proceedings of the National Academy of Sciences* 105(33):11823–11826.

Kemp, A. C., B. P. Horton, J. P. Donnelly, M. E. Mann, M. Vermeer, and S. Rahmstorf. 2011. Climate Related Sea-level Variations over the Past Two Millennia. *Proceedings of the National Academy of Sciences* 108(27):11017–11022.

Keoleian, G. A., and K. Kar. 1999. Life Cycle Design of Air Intake Manifolds: Phase I: 2.0 L Ford Contour Air Intake Manifold. EPA/600/R-99/023. University of Michigan Center for Sustainable Systems.

Khanna, V., and B. R. Bakshi. 2009. Carbon Nanofiber Polymer Composites: Evaluation of Life Cycle Energy Use. *Environmental Science & Technology* 43(6):2078–2084.

Kharaka, Y. K., and J. K. Otton. 2003. Environmental Impacts of Petroleum OroductionProduction: Initial Results from the Osage-Skiatook Petroleum Environmental Research Sites, Osage County, Oklahoma. Water Resources Investigation Report 03-4260. Menlo Park, California, U.S. Department of the Interior, U.S. Geological Survey.

Kim, H. C., and T. J. Wallington. 2013. Life Cycle Assessment of Vehicle Lightweighting: A Physics-Based Model of Mass-Induced Fuel Consumption. *Environmental Science & Technology* 47(24):14358–14366.

Kim, H. C., and T. J. Wallington. 2013. Life-cycle Energy and Greenhouse Gas Emission Benefits of Lightweighting in Automobiles: Review and Harmonization. *Environmental Science & Technology* 47(12):6089–6097.

Kim, H. J., C. McMillian, G. A. Keoleian, and S. J. Skerlos. 2010a. Greenhouse Gas Emissions Payback for Lightweighted Vehicles Using Aluminum and High-Strength Steel. *Journal of Industrial Ecology* 14(6):929–946.

Kim, H. J., G. A. Keoleian, and S. J. Skerlos. 2010b. Economic Assessment of Greenhouse Gas Emissions Reduction by Vehicle Lightweighting Using Aluminum and High Strength Steel. *Journal of Industrial Ecology* 15(1):64–80.

King, J. S., P. J. Hanson, E. Bernhardt, P. DeAngelis, R. J. Norby, and K. S. Pregitzer. 2004. A Multiyear Synthesis of Soil Respiration Responses to Elevated Atmospheric CO_2 from Four Forest FACE Experiments. *Global Change Biology* 10(6):1027–1042.

Kingsley, S. L., M. N. Eliot, L. Carlson, J. Finn, D. L. MacIntosh, H. H. Suh, and G. A. Wellenius. 2014. Proximity of US Schools to Major Roadways: A Nationwide Assessment. *Journal of Exposure Science and Environmental Epidemiology* 24(3):253–259.

Kirilenko, A. 2010. Climate Change Impact on Agriculture: Devils Lake Basin. International Environmental Modelling and Software Society (iEMSs) 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake. Fifth Biennial Meeting. Ottawa, CA.

Knowlton, K., B. Lynn, R. A. Goldberg, C. Rosenzweig, C. Hogrefe, J. K. Rosenthal, and P. L. Kinney. 2007. Projecting Heat-related Mortality Impacts under a Changing Climate in the New York City Region. *American Journal of Public Health* 97(11):2028–2034.

Kocańda, A., and H. Sadlowska. 2008. Automotive Component Development by Means of Hydroforming. *Archives of Civil and Mechanical Engineering* 8(3):55–72.

Koffler, C., and J. Provo. 2012. Comparative Life Cycle Assessment of Aluminum and Steel Truck Wheels. Prepared by PE International, Inc. and Five Winds Strategic Consulting for Alcoa, Inc. *Available at*: http://www.alcoawheels.com/alcoawheels/north_america/en/pdf/Alcoa_Comparative_LCA_of_Truck_Wheels_with_CR_statement.pdf. (Accessed: July 2014).

Kopp, R. E., and D. L. Mauzerall. 2010. Assessing the Climatic Benefits of Black Carbon Mitigation. *Proceedings of the National Academy of Sciences* 107(26):11703–11708.

Körner, C., R. Asshoff, O. Bignucolo, S. Hättenschwiler, S. G. Keel, S. Peláez-Riedl, S. Pepin, R. T. W. Siegwolf, and G. Zotz. 2005. Carbon Flux and Growth in Mature Deciduous Forest Trees Exposed to Elevated CO2. *Science* 309(5739):1360–1362.

Krätli, S., C. Huelsebusch, S. Brooks, and B. Kaufmann. 2013. Pastoralism: A Critical Asset for Food Security under Global Climate Change. *Animal Frontiers* 3(1):42–50.

Krewski D., M. Jerrett, R. T. Burnett, R. Ma, E. Hughes, Y. Shi, M. C. Turner, C. A. Pope III, G. Thurston, E. E. Calle, and M. J. Thun. 2009. Extended Follow-up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. HEI Research Report, 140, Health Effects Institute, Boston, MA. *Available at*: http://pubs.healtheffects.org/getfile.php?u=478. (Accessed: July 2, 2014).

Krist, F. J., Jr., J. R. Ellenwood, M. E. Woods, A. J. McMahan, J. P. Cowardin, D. E. Ryerson, F. J. Sapil, M. O. Zweifler, and S. A. Romero. 2014. 2013–2027 National Insect and Disease Forest Risk Assessment, United States Forest Service, Forest Health Technology Enterprise Team FHTET-14-01. Fort Collins, CO.

Kundzewicz, Z. W., S. Kanae, S. I. Seneviratne, J. Handmer, N. Nicholls, P. Peduzzi, R. Mechler, L. M. Bouweri, N. Arnell, K. Mach, R. Muir-Wood, G. R. Brakenridge, W. Kron, G. Benito, Y. Honda, K. Takahashi, and B. Sherstyukov. 2013. Flood Risk and Climate Change: Global and Regional Perspectives. *Hydrological Sciences Journal* 59(1):1–28.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, J. Rennells, A. DeGaetano, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 1. Climate of the Northeast U.S. NOAA Technical Report NESDIS 142-1. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service. Washington, DC.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, J. Rennells, A. DeGaetano, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 1. Climate of the Northeast U.S. NOAA Technical Report NESDIS 142-1. 87 pgs., National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service. Washington, DC. **citing** Hodgkins, G. A., and R. W. Dudley. 2006. Changes in Late-winter Snowpack Depth, Water Equivalent, and Density in Maine, 1926–2004. *Hydrological Processes* 20(4):741–751.

Kunkel, K., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, C. E. Konrad II, C. M. Fuhrman, B. D. Keim, M. C. Kruk, A. Billot, H. Needham, M. Shafer, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S. NOAA Technical Report. National Oceanic and Atmospheric Administration. Washington, DC, NOAA – National Environmental Satellite, Data, and Information Service.

Kunkel, K., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S. D. Hilberg, M. S. Timlin, L. Stoecker, N. E. Westcott, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 3. Climate of the Midwest U.S. NOAA Technical Report NESDIS 142-3. National Oceanic and Atmospheric Administration. Washington, DC, NOAA – National Environmental Satellite, Data, and Information Service.

Kunkel, K., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, M. C. Kruk, D. P. Thomas, M. Shulski, N. Umphlett, K. Hubbard, K. Robbins, L. Romolo, A. Akyuz, T. Pathak, T. Bergantino, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains, NOAA Technical Report NESDIS 142-4.

Kunkel, K., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 5. Climate of the Southwest U.S. NOAA Technical Report NESDIS 142-5. National Oceanic and Atmospheric Administration. Washington, DC, NOAA – National Environmental Satellite, Data, and Information Service.

Kunkel, K., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 6. Climate of the Northwest U.S. NOAA Technical Report NESDIS 142-6. National Oceanic and Atmospheric Administration. Washington, DC, NOAA – National Environmental Satellite, Data, and Information Service.

LaClair, T. J., and R. Truemner. 2005. Modeling of Fuel Consumption for Heavy-Duty Trucks and the Impact of Tire Rolling Resistance. Reprinted from: Heavy Vehicle Drag Reduction—Overviews, Multiple Trailer-Mounted Devices; Tires, Splash and Spray and Emissions; Full Scale Assessments (SP-1985). Presented at: Commercial Vehicle Engineering Congress and Exhibition, Chicago, Illinois, November 1–3, 2005. Paper SAE 2005-10-3550. SAE International.

Laden, F., J. E. Hart, T. J. Smith, M. E. Davis, and E. Garshick. 2007. Cause-specific Mortality in the Unionized U.S. Trucking Industry. *Environmental Health Perspectives* 115:1192–1196.

Lamarque, J.-F., T. C. Bond, V. Eyring, C. Granier, A. Heil, Z. Klimont, D. Lee, C. Liousse, A. Mieville, B. Owen, M. G. Schultz, D. Shindell, S. J. Smith, E. Stehfest, J. Van Aardenne, O. R. Cooper, M. Kainuma, N. Mahowald, J. R. McConnell, V. Naik, K. Riahi, and D. P. van Vuuren. 2010. Historical (1850–2000) Gridded Anthropogenic and Biomass Burning Emissions of Reactive Gases and Aerosols: Methodology and Application. *Atmospheric Chemistry and Physics* 10(15):4963–5019.

Lan, Q., L. Zhang, G. Li, R. Vermeulen, R. S. Weinberg, M. Dosemeci, S. M. Rappaport, M. Shen, B. P. Alter, Y. Wu, W. Kopp, S. Waidyanatha, C. Rabkin, W. Guo, S. Chanock, R. B. Hayes, M. Linet, S. Kim, S. Yin, N. Rothman, and M. T. Smith. 2004. Hematotoxicity in Workers Exposed to Low Levels of Benzene. *Science* 306(5702):1774–1776.

Landsea, C. W., G. A. Vecchi, L. Bengtsson, and T. R. Knutson. 2010. Impact of Duration Thresholds on Atlantic Tropical Cyclone Counts. *Journal of Climate* 23(10):2508–2519.

Langeveld, J. G., R. P. S. Schilperoort, and S. R. Weijers. 2013. Climate Change and Urban Wastewater Infrastructure: There Is More to Explore. *Journal of Hydrology* 476:112–119.

Larkin, R. P., L. L. Pater, and D. J. Tazik. 1996. Effects of Military Noise on Wildlife. A Literature Review. U.S. Army Construction Engineering Research Laboratory Technical Report 96/21. Champaign, Illinois, DTIC Document.

Lattanzio, R. K. 2014. Canadian Oil Sands: Life-Cycle Assessments of Greenhouse Gas Emissions. Congressional Research Service.

Leadley, P. W., H. M. Pereira, R. Alkemade, J. F. Fernandez-Manjarrés, V. Proença, J. P. W. Scharlemann, and M. J. Walpole. 2010. Biodiversity Scenarios: Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services. Secretariat of the Convention on Biological Diversity. Science Technical Series no. 50. *Available at*: http://www.cbd.int/doc/publications/cbd-ts-50-en.pdf. (Accessed: August 10, 2011).

Lechtenböhmer, S., M. Altmann, S. Capito, Z. Matra, W. Weindrorf, and W. Zitte. 2011. Impacts of Shale Gas and Shale Oil Extraction on the Environment and on Human Health. IP/A/ENVI/ST/2011-07. European Parliament Directorate General for Internal Policies. Policy Department A: Economic and Scientific Policy.

Lee, D-Y, V. M. Thomas, and M. A. Brown. 2013. Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness. *Environmental Science & Technology* (47):8022−8030.

Lee, T.-K., Y. Kim, D. M. Rizzo, and Z. S. Filipi. 2011. Battery Power Management in Heavy-duty HEVs Based on the Estimated Critical Surface Charge. *International Journal of Vehicle Design* 61(1):108–127.

Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber. 2008. Tipping Elements in the Earth's Climate System **citing** Stocker, T. F., and D. G. Wright. 1991. Rapid Transitions of the Ocean's Deep Circulation Induced by Changes in Surface Water Fluxes. Nature 351:729 –732. *Proceedings of the National Academy of Sciences* 105(6):1786–1793.

Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber. 2008. Tipping Elements in the Earth's Climate System **citing** Zickfeld K., B. Knopf, V. Petoukhov, and H. J. Schellnhuber. 2005. Is the Indian Summer Monsoon Stable against Global Change? Geophysical Research Letters 32:L15707. *Proceedings of the National Academy of Sciences* 105(6):1786–1793.

Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber. 2008. Tipping Elements in the Earth's Climate System. *Proceedings of the National Academy of Sciences* 105:1786–1793.

Lepeule, J., F. Laden, D. Dockery, and J. Schwartz. 2012. Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974 to 2009. *Environmental Health Perspectives* 120(7):965–970.

Lewis, A., G. Keoleian, and J. Kelly. 2014. The Potential of Lightweight Materials and Advanced Combustion Engines to Reduce Life Cycle Energy and Greenhouse Gas Emissions. SAE Technical Paper 2014-01-1963.

Li, L., W. Li, and Y. Kushnir. 2011. Variation of North Atlantic Subtropical High Western Ridge and its Implications to the Southeastern US Summer Precipitation. *Climate Dynamics* 39:1401–1412.

Li, L., W. Li, and Y. Deng. 2013. Summer Rainfall Variability over the Southeastern United States and its Intensification in the 21st Century as Assessed by the CMIP5 Models. *Journal of Geophysical Research: Atmospheres* 118:340–354.

Li, T., R. M. Horton, and P. L. Kinney. 2013. Projections of Seasonal Patterns in Temperature-related Deaths for Manhattan, New York. *Nature Climate Change* 3(8):717–721.

Lim, H. 2002. Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices. United States Environmental Protection Agency. EPA420-R-02-025.

Lin, J., D. F. Smith, C. W. Babbit, and T.A. Trabold. 2011. Assessment of Bio-Fuel Options for Solid Oxide Fuel Cell-Based Auxiliary Power Units. 2011 IEEE International Symposium on Sustainable Systems and Technology. Chicago IL. May 16–18, 2011. 1–6.

Lindberg, R. 2007. Nutrients in Lakes and Streams. *Available at*: http://www.waterencyclopedia.com/Mi-Oc/Nutrients-in-Lakes-and-Streams.html. (Accessed: May 23, 2014).

Liu, C., and R. P. Allan. 2013. Observed and Simulated Precipitation Responses in Wet and Dry Regions 1850–2100. *Environmental Research Letters* 8(3): 034002.

Lloyd, S.M., and L.B. Lave. 2003. Life Cycle Economic and Environmental Implications of Using Nanocomposites in Automobiles. *Environmental Science & Technology* 37(15):3458–3466.

Long, S. P., E. A. Ainsworth, A. D. B. Leakey, J. Nösberger, and D. R. Ort. 2006. Food for Thought: Lower-than-expected Crop Yield Stimulation with Rising CO_2 Concentrations. *Science* 312(5782):1918–1921.

Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, M. McGeehin, N. Sheats, L. Backer, C. B. Beard, K. L. Ebi, E. Maibach, R. S. Ostfeld, C. Wiedinmyer, E. Zielinski-Gutiérrez, and L. Ziska. 2014. Human Health. Climate Change Impacts in the United States. T. T. C. R. J. M. Melillo, and G. W. Yohe (eds.), Chapter 9, pp. 220–256.

Luo, Y., S. Bo, W. S. Currie, J. S. Dukes, A. Finzi, U. Hartwig, B. Hungate, R. E. McMurtrie, R. Oren, W. J. Parton, D. E. Pataki, R. M. Shaw, D. R. Zak, and C. B. Field. 2004. Progressive Nitrogen Limitation of Ecosystem Responses to Rising Atmospheric Carbon Dioxide. *Bioscience* 54(8):731–739.

Macartney, S., A. Bishaw, and K. Fontenot. 2013. Poverty Rates for Selected Detailed Race and Hispanic Groups by State and Place: 2007–2011. U.S. Census Bureau. *Available at*: http://www.census.gov/prod/2013pubs/acsbr11-17.pdf. (Accessed: June 2, 2014).

Madhu, M., and J. Hatfield. 2013. Dynamics of Plant Root Growth under Increased Atmospheric Carbon Dioxide. Agronomy Journal 105(3):657–669.

Majeau-Bettez, G., T. R. Hawkins, and A. H. Strømman. 2011. Life Cycle Environmental Assessment of Lithium-ion and Nickel Metal Hydride Batteries for Plug-in Hybrid and Battery Electric Vehicles. *Environmental Science & Technology* 45(10):4548–4554.

Maldonado, J. K., C. Shearer, R. Bronen, K. Peterson, and H. Lazrus. 2013. The Impact of Climate Change on Tribal Communities in the US: Displacement, Relocation, and Human Rights. *Climatic Change* 120(3):601–614.

Mammetti, M., D. Gallegos, A. Freixas, and J. Munoz. 2013. The Influence of Rolling Resistance on Fuel Consumption in Heavy-Duty Vehicles. Paper SAE 2013-01-1343. SAE International.

Mann, M. E., and K. A. Emanuel. 2006. Atlantic Hurricane Trends Linked to Climate Change. EOS, Transactions American Geophysical Union 87(24):233–241.

Marten, A. L., and S. C. Newbold. 2011. Estimating the Social Cost of Non-CO2 GHG Emissions: Methane and Nitrous Oxide. *Energy Policy* (51):957–972.

Marten, A. L., E. A. Kopits, C. W. Griffiths, S. C. Newbold & A. Wolverton. 2014. Incremental CH_4 and N_2O mitigation benefits consistent with the US Government's SC-CO_2 estimates, Climate Policy, DOI: 10.1080/14693062.2014.912981. *Available at*: http://www.tandfonline.com/doi/full/10.1080/14693062.2014.912981. (Accessed: June 17, 2015).

Martinich, J., J. Neumann, L. Ludwig, and L. Jantarasami. 2013. Risks of Sea Level Rise to Disadvantaged Communities in the United States. *Mitigation and Adaptation Strategies for Global Change* 18(2):169–185.

Marzeion, B., and A. Levermann. 2014. Loss of Cultural World Heritage and Currently Inhabited Places to Sea-Level Rise. *Environmental Research Letters* 9(3):7.

Maryland Port Administration. 2008. The Economic Impacts of the Port of Baltimore. Martin Associates. Lancaster, PA.

Matonse, A. H., D. C. Pierson, A. Frei, M. S. Zion, A. Anandhi, E. Schneiderman, and B. Wright. 2013. Investigating the Impact of Climate Change on New York City's Primary Water Supply. *Climatic Change* 116(3–4):437–456.

Matthews, H. D., and K. Caldeira. 2008. Stabilizing Climate Requires Near-Zero Emissions. *Geophysical Research Letters* 35(4).

Mayyas, A.T., A. Qattawi, A.R. Mayyas, and M.A. Omar. 2012. Life Cycle Assessment-Based Selection for Sustainable Lightweight Body-in-White Design. *Energy* 39:411–425.

McConnell, R., T. Islam, K. Shankardass, M. Jerrett, F. Lurmann, F. Gilliland, J. Gauderman, E. Avol, N. Künzli, L. Yao, J. Peters, and K. Berhane. 2010. Childhood Incident Asthma and Traffic-related Air Pollution at Home and School. *Environmental Health Perspectives* 1021–1026.

McGrath, J. M., and D. B. Lobell. 2013. Regional Disparities in the CO_2 Fertilization Effect and Implications for Crop Yields. *Environmental Research Letters* 8(1):014054

McGrath, J. M., and D. B. Lobell. 2013. Regional Disparities in the CO_2 Fertilization Effect and Implications for Crop Yields **citing** Ainsworth, E. A., and A. Rogers. 2007. The Response of Photosynthesis and Stomatal Conductance to Rising [CO2]: Mechanisms and Environmental Interactions. Plant, Cell & Environment 30(3):258–270. *Environmental Research Letters* 8(1):014054.

McGrath, J. M., and D. B. Lobell. 2013. Regional disparities in the CO_2 fertilization effect and implications for crop yields **citing** Bernacchi, C. J., B. A. Kimball, D. R. Quarles, S. P. Long, and D. R. Ort. 2007. Decreases in Stomatal Conductance of Soybean under Open-air Elevation of [CO2] Are Closely Coupled with Decreases in Ecosystem Evapotranspiration. *Plant Physiology* 143(1):134–144. Environmental Research Letters 8(1):014054.

McGrath, J. M., and D. B. Lobell. 2013. Regional Disparities in the CO_2 Fertilization Effect and Implications for Crop Yields **citing** Conley, M. M., B. A. Kimball, T. J. Brooks, P. J. Pinter, D. J. Hunsaker, G. W. Wall, and J. M. Triggs. 2001. CO2 Enrichment Increases Water-use Efficiency in Sorghum. *New Phytologist* 151(2):407–412. *Environmental Research Letters* 8(1): 014054.

McGrath, J. M., and D. B. Lobell. 2013. Regional disparities in the CO_2 fertilization effect and implications for crop yields **citing** Hunsaker, D. J., B. A. Kimball, P. J. Pinter Jr., G. W. Wall, R. L. LaMorte, F. J. Adamsen, and T. J. Brooks. 2000. CO2 Enrichment and Soil Nitrogen Effects on Wheat Evapotranspiration and Water Use Efficiency. *Agricultural and Forest Meteorology* 104(2):85–105. *Environmental Research Letters* 8(1):014054.

McGrath, J. M., and D. B. Lobell. 2013. Regional Disparities in the CO_2 Fertilization Effect and Implications for Crop Yields **citing** Leakey, A. D. 2009. Rising Atmospheric Carbon Dioxide

Concentration and the Future of C4 Crops for Food and Fuel. Proceedings of the Royal Society B: Biological Sciences 276(1666):2333–2343. *Environmental Research Letters* 8(1): 014054.

McGrath, J. M., and D. B. Lobell. 2013. Regional Disparities in the CO_2 Fertilization Effect and Implications for Crop Yields **citing** Leakey, A. D. B., C. J. Bernacchi, F. G. Dohleman, D. R. Ort, and S. P. Long. 2004. Will Photosynthesis of Maize (zea mays) in the US Corn Belt Increase in Future [CO2] Rich Atmospheres? An Analysis of Diurnal Courses of CO_2 Uptake under Free-Air Concentration Enrichment (face). *Global Change Biology* 10(6):951–962. *Environmental Research Letters* 8(1): 014054.

McGrath, J. M., and D. B. Lobell. 2013. Regional Disparities in the CO_2 Fertilization Effect and Implications for Crop Yields **citing** Leakey, A. D., C. J. Bernacchi, D. R. Ort, and S. P. Long. 2006. Long-term Growth of Soybean at Elevated [CO_2] Does Not Cause Acclimation of Stomatal Conductance under Fully Open-Air Conditions. Plant, Cell & Environment 29(9):1794–1800. *Environmental Research Letters* 8(1):014054.

Medina-Ramón, M., and J. Schwartz. 2007. Temperature, Temperature Extremes, and Mortality: A Study of Acclimatisation and Effect Modification in 50 US Cities. *Occupational and Environmental Medicine* 64(12):827–833.

Meehl, G. A., J. M. Arblaster, and W. D. Collins. 2008. Effects of Black Carbon Aerosols on the Indian Monsoon. *Journal of Climate* 21(12):2869–2882.

Meehl, G.A., T. F. Stocker, W. D. Collins, P. Friedlingstein, A. T. Gaye, J. M. Gregory, A. Kitoh, R. Knutti, J. M. Murphy, A. Noda, S. C. B. Raper, I. G. Watterson, A. J. Weaver, and Z. C. Zhao. 2007. Global Climate Projections. Pages 747–846 in: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.)]. Cambridge University Press: Cambridge, United Kingdom and New York, NY. 996 pgs. *Available at*: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. (Accessed: February 16, 2015).

Meinshausen, M., S. C. B. Raper, and T. M. L. Wigley. 2011. Emulating Coupled Atmosphere-Ocean and Carbon Cycle Models with a Simpler Model, MAGICC6–Part 1: Model Description and Calibration. *Atmospheric Chemistry and Physics* 11(4):1417–1456.

Mengel, M., and A. Levermann. 2014. Ice Plug Prevents Irreversible Discharge from East Antarctica. *Nature Climate Change* 4(6):451–455. doi:10.1038/nclimate2226.

Mitchum, G. 2011. Sea Level Changes in the Southeastern United States: Past, Present, and Future. University of South Florida, Florida Climate Institute and Southeast Climate Consortium.

Mohai, P., P. M. Lantz, J. Morenoff, J. S. House, and R. P. Mero. 2009. Racial and Socioeconomic Disparities in Residential Proximity to Polluting Industrial Facilities: Evidence from the Americans' Changing Lives Study. *American Journal of Public Health* 99(S3):S649–S656.

Mohapatra, S., and S. Das. 2014. Introduction of High Strength Steel for Commercial Vehicles—Light Weighting of Vehicles. SAE Technical Paper 2014-28-0002.

Montag, J. M., K. Swan, K. Jenni, T. Nieman, J. Hatten, M. Mesa, D. Graves, F. Voss, M. Mastin, J. Hardiman, and A. Maule. 2014. Climate Change and Yakama Nation Tribal Well-being. *Climatic Change* 124(1–2):385–398.

Montoya, J. M., and D. Raffaelli. 2010. Climate Change, Biotic Interactions and Ecosystem Services. Philosophical Transactions of the Royal Society B: Biological Sciences 365(1549):2013–2018.

Morello-Frosch, R. 2002. Discrimination and the Political Economy of Environmental Inequality. *Environment and Planning C: Government & Policy* 20(4):477–496.

Morris, J. B., P. T. Symanowicz, J. E. Olsen, R. S. Thrall, M. M. Cloutier, and A. K. Hubbard. 2003. Immediate Sensory Nerve-Mediated Respiratory Responses to Irritants in Healthy and Allergic Airway-Diseased Mice. *Journal of Applied Physiology* 94(4):1563–1571.

Moss, R. H., and S. H. Schneider. 2000. Uncertainties in the IPCC TAR: Recommendations to Lead Authors for More Consistent Assessment and Reporting. Guidance Papers on the Crosscutting Issues of the Third Assessment Report of the IPCC. Cambridge, UK.

Müller, C., and R. D. Robertson. 2014. Projecting Future Crop Productivity for Global Economic Modeling. *Agricultural Economics* 45(1):37–50.

Munday, P. L., A. J. Cheal, D. L. Dixson, J. L. Rummer, and K. E. Fabricius. 2014. Behavioral Impairment in Reef Fishes Caused by Ocean Acidification at CO_2 Seeps. Nature Climate Change (4):487–492. doi: 10.1038/nclimate2195.

Myhre, G., B. H. Samset, M. Schulz, Y. Balkanski, S. Bauer, T. K. Berntsen, H. Bian, N. Bellouin, M. Chin, T. Diehl, R. C. Easter, J. Feichter, S. J. Ghan, D. Hauglustaine, T. Iversen, S. Kinne, A. Kirkevåg, J.-F. Lamarque, G. Lin, X. Liu, M. T. Lund, G. Luo, X. Ma, T. van Noije, J. E. Penner, P. J. Rasch, A. Ruiz, Ø. Seland, R. B. Skeie, P. Stier, T. Takemura, K. Tsigaridis, P. Wang, Z. Wang, L. Xu, H. Yu, F. Yu, J.-H. Yoon, K. Zhang, H. Zhang, and C. Zhou. 2013. Radiative Forcing of the Direct Aerosol Effect from AeroCom Phase II Simulations. *Atmospheric Chemistry and Physics* 13(4):1853–1877.

Myou, S., M. Fujimura, K. Nishi, T. Ohka, and T. Matsuda. 1993. Aerosolized Acetaldehyde Induces Histamine-Mediated Bronchoconstriction in Asthmatics. *American Review of Respiratory Disease* 148(4 pt. 1):940–943.

NACFE (North American Council for Freight Efficiency). 2010. Executive Report—Wide Base Tires. North American Council for Freight Efficiency. *Available at*: http://nacfe.org/wp-content/uploads/2010/12/NACFE-ER-1002-Wide-Base-Tires-Dec-2010.pdf. (Accessed: July 16, 2014).

NAS (National Academy of Sciences). 2006. National Research Council, Transportation Research Board, Special Report 286 – Tires and Passenger Vehicle Fuel Economy – Informing Consumers, Improving Performance. *Available at*: http://www.nap.edu/catalog/11620.html. (Accessed: January 7, 2015).

NAS. 2010. Vehicle Technologies for Reducing Load-Specific Fuel Consumption. Chapter 5 in: Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles. National Academies Press. Washington, DC. 251 pgs.

NAS. 2014a. Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: First Report. Committee on Assessment of Technologies and Approaches

for Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. National Academies Press. Washington, DC. 162 pgs.

NAS. 2014b. Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report.

National Academy of Engnieering. 2010. Technology for a Quieter America. Available at: http://www.nap.edu/catalog/12928/technology-for-a-quieter-america. (Accessed: June 17, 2015).

National Research Council Canada. 2012. Technical Report: Review of Aerodynamic Drag Reduction Devices for Heavy Trucks and Buses. Centre for Surface Transportation Technology. *Available at*: https://www.tc.gc.ca/eng/programs/environment-etv-menu-eng-2939.html. (Accessed: July 10, 2014).

National Science and Technology Council. 2008. Scientific Assessment of the Effects of Global Change on the United States. A Report of the Committee on Environment and Natural Resources Prepared for the U.S. National Science and Technology Council. Washington, DC.

National Science and Technology Council. 2008. Scientific Assessment of the Effects of Global Change on the United States. A Report of the Committee on Environment and Natural Resources Prepared for the U.S. National Science and Technology Council **citing** Forister, M. L., and A. M. Shapiro. 2003. Climatic Trends and Advancing Spring Flight of Butterflies in Lowland California. Global Change Biology 9(7):1130–1135. Washington, DC.

NCHRP (National Cooperative Highway Research Program). 2014. Strategic Issues Facing Transportaion Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report. National Cooperative Highway Research Prorgram Report 750. Washington, DC, Transportation Research Board.

Nelson, F., L. Brigham, K. Hinkel, W. Parker, V. Romanovsky, N. Shiklomanov, O. Smith, W. Tucker, and T. Vinson. 2003. Climate Change, Permafrost, and Impacts on Civil Infrastructure. Special Report 01-03. US Arctic Research Commission.

Nelson, G. C., D. van der Mensbrugghe, T. Hasegawa, K. Takahashi, R. Sands, P. Kyle, K. Calvin, P. Havlik, H. Valin, D. Mason d'Croz, A. Kavallari, A. Tabeau, C. Schmitz, H. Lotze-Campen, C. Müller, and M. von Lampe. 2014. Agriculture and Climate Change in Global Scenarios: Why Don't the Models Agree. *Agricultural Economics* 45(1):85–101.

New York City Panel on Climate Change. 2013. Climate Risk Information 2013: Observations, Climate Change Projections, and Maps. City of New York Special Initiative on Rebuilding and Resiliancy. New York, NY.

NHTSA (National Highway Traffic Safety Administration). 2009. NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2—Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy. DOT HS 811 154.

NHTSA. 2010. Factors and Considerations for Establishing a Fuel Efficiency Regulatory Program for Commercial Medium- and Heavy-Duty Vehicles. U.S. Department of Transportation.

NHTSA. 2010. Final Environmental Impact Statement, Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2012–2016. Washington, DC, National Highway Traffic Safety Administration.

NHTSA. 2010. Quiet Car Notice of Intent: Notice of Intent to Prepare an Environmental Assessment for Pedestrian Safety Enhancement Act of 2010 Rulemaking.

NHTSA. 2011. Final Environmental Impact Statement, Medium and Heavy-Duty Fuel Efficiency Improvement Program. Washington, DC, National Highway Traffic Safety Administration.

NHTSA. 2012. Final Environmental Impact Statement, Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2017–2025. Washington, DC, National Highway Traffic Safety Administration.

NHTSA. 2012. Final Environmental Impact Statement, Corporate Average Fuel Economy Standards Passenger Cars and Light Trucks, Model Years 2017–2025, Docket No. NHTSA-2011-0056. July 2012. *Available at*: http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Environmental+Impact+Statement+for+CAFE+Standards,+2017-2025. (Accessed: November 6, 2014).

NHTSA and EPA. 2011. 2017–2025 Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: Supplemental Notice of Intent. *Available at*: http://www.epa.gov/oms/climate/proposedregs.htm. (Accessed: June 17, 2015).

Nicholls, R. J., and A. Cazenave. 2010. Sea-level Rise and its Impact on Coastal Zones. *Science* 328(5985):1517–1520.

Nicholls, R. J., S. Hanson, J. A. Lowe, R. A. Warrick, X. Lu, A. J. Long, and T. A. Carter. 2011. Constructing Sea-Level Scenarios for Impact and Adaptation Assessment of Coastal Areas: A Guidance Document. Supporting Material, Intergovernmental Panel on Climate Change Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA), Geneva, Switzerland.

NOAA (National Oceanic and Atmospheric Administration). 2010. States and Territories Working on Ocean and Coastal Management. *Available at*: http://coastalmanagement.noaa.gov/mystate/welcome.html. (Accessed: June 19, 2014).

NOAA. 2011. The Ozone Layer. *Available at*: http://esrl.noaa.gov/csd/ozonelayer.html. (Accessed: April 20, 2015).

NOAA. 2012. Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Technical Report OAR CPO-1.

NOAA. 2012. Marine Education – Thermocline. Last revised: April 15, 2012. *Available at*: http://www.erh.noaa.gov/cle/marine/marine_education/thermocline.php. (Accessed: February 16, 2015).

NOAA. 2012. NOAA's State of the Coast: The U.S. Population Living at the Coast. *Available at*: http://stateofthecoast.noaa.gov/population/welcome.html. (Accessed: June 3, 2014).

NOAA. 2014. Globally Averaged Marine Surface Annual Mean CO2 Data. *Available at*: ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_gl.txt. (Accessed: April 22, 2015).

Norby, R. J., E. H. DeLucia, B. Gielen, C. Calfapietra, C. P. Giardina, J. S. King, J. Ledford, H. R. McCarthy, D. J. P. Moore, R. Ceulemans, P. De Angelis, A. C. Finzi, D. F. Karnosky, M. E. Kubiske, M. Lukac, K. S. Pregitzer, G. E. Scarascia-Mugnozza, W. H. Schlesinger, and R. Ore. 2005. Forest Response to Elevated CO2 Is Conserved across a Broad Range of Productivity. *Proceedings of the National Academy of Sciences of the United States of America* 102(50):18052–18056.

Notter, D. A., M. Gauch, R. Widmer, P. Wäger, A. Stamp, R. Zah, and H-J. Althaus. 2010. Contribution of Li-ion Batteries to the Environmental Impact of Electric Vehicles. *Environmental Science & Technology* 44(17):6550–6556.

NRC (National Research Council of the National Academies). 2008. Progress Toward Restoring the Everglades: The Second Biennial Review. Washington, DC, The National Academies Press.

NRC. 2010. Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. National Academies Press. Washington, DC.

NRC. 2011a. Review of the Environmental Protection Agency's Draft IRIS Assessment of Formaldehyde. Washington, DC, National Academies Press: 194 pgs.

NRC. 2011b. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. National Academies Press, Washington, DC.

NRC. 2013a. Climate and Social Stress: Implications for Security Analysis. National Research Council.

NRC. 2013b. Abrupt Impacts of Climate Change: Anticipating Surprises. National Research Council (NRC). *Available at*: http://www.nap.edu/catalog.php?record_id=18373. (Accessed: February 16, 2015).

NRC. 2011c. National Security Implications of Climate Change for U.S. Naval Forces.

NRC. 2014. Reducing Fuel Consumption and Greenhouse Gas Emission of Medium- and Heavy-Duty Vehicles: Phase 2. Washington, DC: 233 pgs.

NRC – Auffhammer, M. 2011. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. Washington, DC, National Institute of Environmental Health Science: National Academies Press.

NREL (National Renewable Energy Laboratory). 2006. Effects of Biodiesel Blends on Vehicle Emissions. NREL/MP-540-40554. National Renewable Energy Laboratory. *Available at*: http://www.nrel.gov/docs/fy07osti/40554.pdf. (Accessed: July 8, 2014).

NREL. 2008. Biodiesel Handling and Use Guide, Fourth Edition. NREL/TP-540-43672. National Renewable Energy Laboratory. *Available at*: http://www.nrel.gov/docs/fy09osti/43672.pdf. (Accessed: July 2014).

NTP (National Toxicology Program). 2011. Report on Carcinogens. U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.

Office of Management and Budget, Update of Statistical Area Definitions and Guidance on Their Uses, 2009. *Available at*: http://www.whitehouse.gov/sites/default/files/omb/assets/bulletins/b10-02.pdf. (Accessed: February 16, 2015).

Olsson, Ann C., et al. "Exposure to diesel motor exhaust and lung cancer risk in a pooled analysis from case-control studies in Europe and Canada." *American Journal of Respiratory and Critical Care Medicine* 183.7(2011):941-948.

O'Neill, M. S., M. Jerrett, I. Kawachi, J. I. Levy, A. J. Cohen, N. Gouveia, P. Wilkinson, T. Fletcher, L. Cifuentes, and J. Schwartz. 2003. Health, Wealth, and Air Pollution: Advancing Theory and Methods. *Environmental Health Perspectives* 111(16):1861–1870.

O'Neill, M. S., A. Zanobetti, and J. Schwartz. 2005. Disparities by Race in Heat-Related Mortality in Four US Cities: The Role of Air Conditioning Prevalence. *Journal of Urban Health* 82(2):191–197.

ORNL (Oak Ridge National Laboratory). 2013. Vehicle Technologies: Market Report.

O'Rourke, D., and S. Connolly. 2003. Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption. *Annual Review of Environment and Resources* 28(1):587–617.

Ostro, B. D., L. A. Roth, R. S. Green, and R. Basu. 2009. Estimating the Mortality Effect of the July 2006 California Heat Wave. *Environmental Research* 109(5):614–619.

Oswald-Spring, Ú. 2014. Social and Environmental Vulnerability in a River Basin of Mexico. Expanding Peace Ecology: Peace, Security, Sustainability, Equity and Gender. S*pringer Briefs in Environment, Security, Development and Peace*, pgs 85–109.

Ouis, D. 2001. Annoyance from Road Traffic Noise: A Review. *Journal of Environmental Psychology* 21(1):101–120.

Overly, J.G., R. Dhingra, G.A. Davis, and S. Das. 2002. Environmental Evaluation of Lightweight Exterior Body Panels in New Generation Vehicles. Paper 2002-01-1965. SAE, International.

Pallas, M.-A., R. Chatagnon, and J. Lelongl. 2014. Noise Emission Assessment of a Hybrid Electric Mid-size Truck. *Applied Acoustics* 76:280–290.

Passchier-Vermeer, W., and W. F. Passchier. 2000. Noise Exposure and Public Health. *Environmental Health Perspectives* 108(Suppl 1):123–131.

Pastor, M., J. Sadd, and J. Hipp. 2001. Which Came First? Toxic Facilities, Minority Move-in, and Environmental Justice. *Journal of Urban Affairs* 23(1):1–21.

Patterson, J., M. Alexander, and A. Gurr. 2011. Preparing for a Life Cycle CO_2 Measure. Ricardo plc and Low Carbon Vehicle Partnership. RD.11/124801.4.

Patterson, L. A., B. Lutz, and M. W. Doyle. 2013. Climate and Direct Human Contributions to Changes in Mean Annual Streamflow in the South Atlantic, USA. *Water Resources Research* 49(11):7278–7291.

Payne, B., and R. Ackley. 2012. Report to the Clean Air Council on 8 June, 2012 Field Inspection and Methane Sampling Survey of Parts of Leroy, Granville and Franklin Townships, Bradford County, PA.

Peischl, J., T.B. Ryerson, J. Brioude, K.C. Aikin, A.E. Andrews, E. Atlas, D. Blake, B.C. Daube, J.A. deGouw, E. Dlugokencky, G.J. Frost, D.R. Gentner, J.B. Gilman, A.H. Goldstein, R.A. Harley, J.S. Holloway, J. Kofler, W.C. Kuster, P.M. Lang, P.C. Novelli, G.W. Santoni, M. Trainer, S.C. Wofsy, and D.D. Parrish. 2013. Quantifying Sources of Methane Using Light Alkanes in the Los Angeles Basin, CA. Journal of Geophysical Research: Atmospheres 118:4974–4990.

Perera, F. P., V. Rauh, W. Y. Tsai, P. Kinney, D. Camann, D. Barr, T. Bernert, R. Garfinkel, Y. H. Tu, D. Diaz, J. Dietrich, and R. M. Whyatt. 2003. Effects of Transplacental Exposure to environmental Pollutants on Birth Outcomes in a Multiethnic Population. *Environmental Health Perspectives* 111(2):201–205.

Perera, F. P., V. Rauh, R. M. Whyatt, W. Y. Tsai, D. Tang, D. Diaz, L. Hoepner, D. Barr, Y. H. Tu, D. Camann, and P. Kinney. 2006. Effect of Prenatal Exposure to Airborne Polycyclic Aromatic Hydrocarbons on Neurodevelopment in the First 3 Years of Life among Inner-City Children. *Environmental Health Perspectives* 11(8):1287–1292.

Perry, D. 1994. Forest Ecosystems **citing** Schneider, S.H., and R. Londer. 1984. The Coevolution of Climate and Life. Sierra Club Books. San Francisco, California. Baltimore, MD, Johns Hopkins University Press.

Peters, A., S. von Klot, M. Heier, I. Trentinaglia, A. Hörmann, H. E. Wichmann, and H. Löwel. 2004. Exposure to Traffic and the Onset of Myocardial Infarction. *New England Journal of Medicine* 351:1721–1730.

Pétron, G., G. Frost, B.R. Miller, A.I. Hirsch, S.A. Montzka, A. Karion, M. Trainer, C. Sweeney, A.E. Andrews, L. Miller, J. Kofler, A. Bar-Ilan, E.J. Dlugokencky, L. Patrick, C.T. Moore, Jr., T.B. Ryerson, C. Siso, W. Kolodzey, P.M. Lang, T. Conway, P. Novelli, K. Masarie, B. Hall, D. Guenther, D. Kitzis, J. Miller, D. Welsh, D. Wolfe, W. Neff, and P. Tans. 2012. Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study. *Journal of Geophysical Research* 117(D4):1–19.

PEW (Pew Center on Global Climate Change). 2011 Reducing Greenhouse Gas Emissions from U.S. Transportation. Pew Center on Global Climate Change. *Available at*: http://www.c2es.org/docUploads/reducing-transportation-ghg.pdf. (Accessed: July 2014).

Phillips, N.G., R. Ackley, E.R. Crosson, A. Down, L.R. Hutyra, M. Brondfield, J.D. Karr, K. Zhao, and R.B. Jackson. 2012. Mapping Urban Pipeline Leaks: Methane Levels Across Boston. *Environmental Pollution* 173(2013):1–4.

Pimm, S. 2009. Climate disruption and biodiversity **citing** Moritz, C., J.L. Patton, C.J. Conroy, J.L. Parra, G.C. White, and S.R. Beissinger. 2008. Impact of a Century of Climate Change on Small-mammal Communities in Yosemite National Park, USA. Science 322:261. *Current Biology* 19(14): R595–R601.

Pinkerton, L., M. J. Hein, and L. T. Stayner. 2004. Mortality Among a Cohort of Garment Workers Exposed to Formaldehyde: An Update. *Occupational and Environmental Medicine* 61(3):193–200.

Plant, N. G., H. F. Stockdon, A. H. Sallenger Jr., M. J. Turco, J. W. East, A. A. Taylor, and W. A. Shaffer. 2010. Forecasting Hurricane Impact on Coastal Topography. *EOS, Transactions American Geophysical Union* 91(7):65–72.

Potti, J. 2008. Temperature during Egg Formation and the Effect of Climate Warming on Egg Size in a Small Songbird. *Acta Oecologica* 33(3):387–393.

Power, M.C., Weisskopf, M.G., Alexeef, S.E., et al. 2011. Traffic-related air pollution and cognitive function in a cohort of older men. *Environmental Health Perspective* 682–687 pgs.

Preston, B. L. 2006. Risk-based Reanalysis of the Effects of Climate Change on US Cold-water Habitat. *Climatic Change* 76(1–2):91–119.

Pritchard, S. 2011. Soil Organisms and Global Climate Change. *Plant Pathology* 60(1):82–99.

Prudhomme, C., I. Giuntoli, E. L. Robinson, D. B. Clark, N. W. Arnell, R. Dankers, B. M. Fekete, W. Franssen, D. Gerten, S. N. Gosling, S. Hagemann, D. M. Hannah, H. Kim, Y. Masaki, Y. Satoh, T. Stacke, Y. Wada, and Dominik Wissernl. 2014. Hydrological Droughts in the 21st Century, Hotspots and Uncertainties from a Global Multimodel Ensemble Experiment. Proceedings of the National Academy of Sciences 111(9):3262–3267.

Pukkala, E. 1998. Cancer Incidence among Finnish Oil Refinery Workers, 1971–1994. J*ournal of Occupational and Environmental Medicine* 40(8):675–679.

Qu, Q., R. Shore, G. Li, X. Jin, L. C. Chen, B. Cohen, A. A. Melikian, D. Eastmond, S. M. Rappaport, S. Yin, H. Li, S. Waidyanatha, Y. Li, R. Mu, X. Zhang, and K. Li. 2002. Hematological Changes among Chinese Workers with a Broad Range of Benzene Exposures. *American Journal of Industrial Medicine* 42(4):275–285.

Qu, Q., R. Shore, G. Li, X. Jin, L. C. Chen, B. Cohen, A. A. Melikian, D. Eastmond, S. Rappaport, H. Li, D. Rupa, S. Waidyanatha, S. Yin, H. Yan, M. Meng, W. Winnik, E. S. Kwok, Y. Li, R. Mu, B. Xu, X. Zhang, and K. Li. 2003. Validation and Evaluation of Biomarkers in Workers Exposed to Benzene in China. *Research Report (Health Effects Institute)(115*):1–72; Discussion 73–87.

Quinn, P., T. S. Bates, E. Baum, N. Doubleday, A. M. Fiore, M. Flanner, A. Fridlind, T. J. Garrett, D. Koch, S. Menon, D. Shindell, A. Stohl, and S. G. Warren. 2008. Short-lived Pollutants in the Arctic: Their Climate Impact and Possible Mitigation Strategies. *Atmospheric Chemistry and Physics* 8(6):1723–1735.

Raaschou-Nielsen, O., and P. Reynolds. 2006. Air Pollution and Childhood Cancer: A Review of the Epidemiological Literature. International Journal of Cancer 118(12):2920–2929. doi: 10.1002/ijc.21787. *Available at*: http://onlinelibrary.wiley.com/doi/10.1002/ijc.21787/pdf. (Accessed: February 16, 2015).

Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea-level Rise. Science 315(5810):368-370. doi: 10.1029/2007GL032486.

Ramanathan, V., and G. Carmichael. 2008. Global and Regional Climate Changes due to Black Carbon. *Nature Geoscience* 1(4):221–227.

Rauscher, S. A., J. S. Pal, N. S. Diffenbaugh, and M. M. Benedetti. 2008. Future Changes in Snowmelt-driven Runoff Timing over the Western US. Geophysical Research Letters 35(16:L16703).

Ravishankara, A., M. J. Kurylo, C. A. Ennis, J. Blunden, A. M. Waple, and C. Zammara (eds.). 2008. Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Commerce. Asheville, NC.

Reader, M. C., D. A. Plummer, J. F. Scinocca, and T. G. Shepherd. 2013. Contributions to Twentieth Century Total Column Ozone Change from Halocarbons, Tropospheric Ozone Precursors, and Climate Change. *Geophysical Research Letters* 40(23):6276–6281.

RGGI (Regional Greenhouse Gas Initiative). 2009. Fact Sheet: The Regional Greenhouse Gas Initiative (RGGI): About RGGI Benefits. *Available at*: https://home-performance.org/news/documents/RGGI_Fact_Sheet.pdf. (Accessed: June 17, 2015).

RGGI. 2014. The RGGI CO2 Cap. Retrieved June 26, 2014. *Available at*: http://www.rggi.org/design/overview/cap. (Accessed: February 16, 2015).

Richardson, M., and B. Haylock. 2012. Design/Maker: The Rise of Additive Manufacturing, Domestic-Scale Production and the Possible Implications for the Automotive Industry. *Computer-Aided Design & Application PACE* (2):33–48.

Ridge Corporation, 2014. Proven Fuel Savings…Mile After Mile Green Wing Aerodynamic Side Skirts. *Available at*: http://ridgecorp.com/site/files/green_wing_gen2.pdf. (Accessed: July 2014).

Riediker, M. 2007. Cardiovascular effects of fine particulate matter components in highway patrol officers. Inhalation Toxicology 19:99–105. doi: 10.1080/08958370701495238.

Rignot, E., J. Mouginout, M. Morlighem, H. Seroussi, and B. Scheeuchl. 2014. Widespread, Rapid Grounding Line Retreat of Pine Island, Thwaites, Smith, and Kohler Glaciers, West Antarctica, from 1992 to 2011. *Geophysical Research Letters* 41:3502–3509.

Rignot, E., I. Velicogna, M. van den Broeke, A. Monaghan, and J. Lenaerts. 2011. Acceleration of the Contribution of the Greenland and Antarctic Ice Sheets to Sea Level Rise. *Geophysical Research Letters* 38(5):L05503. doi: 10.1029/2011GL046583.

Robbins, C., S. Hoekman, A. Gertler, A. Broch, and M. Natarajan. 2009. Biodistillate Transportation Fuels 2 –Emissions Impacts. Technical Paper. Society of Automotive Engineers. *Available at*: http://papers.sae.org/2009-01-2724/. (Accessed: July 2014).

Rochlin, I., D. V. Ninivaggi, M. L. Hutchinson, and A. Farajollahi. 2013. Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA: Implications for Public Health Practitioners. PLoS ONE 8:e60874. Washington DC: U.S. Global Change Research Program.

Rooks, B. 2001. Tailor-Welded Blanks Bring Multiple Benefits to Car Design. *Assembly Automation* 21(4):323–329.

Rosenthal, D. M., and N. J. Tomeo. 2013. Climate, Crops and Lacking Data Underlie Regional Disparities in the CO2 Fertilization Effect. *Environmental Research Letters* 8(3):031001.

Rothman, N., G. L. Li, M. Dosemeci, W. E. Bechtold, G. E. Marti, Y. Z. Wang, M. Linet, L. Q. Xi, W. Lu, M. T. Smith, N. Titenko-Holland, L. P. Zhang, W. Blot, S. N. Yin, and R. B. Hayes. 1996. Hematotoxocity among Chinese Workers Heavily Exposed to Benzene. American Journal of Industrial Medicine 29(3):236–246.

Routhier, B. 2007. New Generation Wide Base Single Tires. American Trucking Associations. Presented at the International Workshop on the Use of Wide-Base Tires, October 25–26, 2007. Federal Highway Administration. *Available at*: http://www.arc.unr.edu/Workshops/Wide-Base_Tires/Wide_Base_Summary-v9-ATA-whitepaper.pdf. (Accessed: July 16, 2014).

Rowangould, G. M. 2013. A Census of the US Near-roadway Population: Public Health and Environmental Justice Considerations. T*ransportation Research Part D: Transport and Environment* 25:59–67.

Roy, S. B., L. Chen, E. H. Girvetz, E. P. Maurer, W. B. Mills,and T. M. Grieb. 2012. Projecting Water Withdrawal and Supply for Future Decades in the U.S. under Climate Change Scenarios. *Environmental Science & Technology* 46:2545−2556.

Rutgers. 2014. Appellate Division Tells NJDEP it Must Amend/Repeal RGGI Rules, Gives Legislature an Opening. Last revised: March 27, 2014. *Available at*: http://www.rutgerspolicyjournal.org/appellate-division-tells-njdep-it-must-amendrepeal-rggi-rules-gives-legislature-opening. (Accessed: May 23, 2014).

SA Concepts. 2014. Aerosmart Trailer Skirting, *Available at*: http://sa-concepts.com/?page_id=21. (Accessed: July 2014).

Salam, M. T., T. Islam, and F. D. Gilliland. 2008. Recent Evidence for Adverse Effects of Residential Proximity to Traffic Sources on Asthma. *Current Opinion in Pulmonary Medicine* 14(1):3–8.

Salman, O., and Y. Chen. 2013. Comparative Environmental Analysis of Conventional and Hybrid Wheel Loader Technologies—A Life Cycle Perspective. Master of Science Thesis. Stockholm, Sweden: Royal Institute of Technology.

Samaras, C., and K. Meisterling. 2008. Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy. Environmental Science & Technology 42(9):3170–3176. *Available at*: http://pubs.acs.org/doi/pdf/10.1021/es702178s. (Accessed: July 2014).

Samet, J. M. 2007. Traffic, Air Pollution, and Health. *Inhalation Toxicology* 19(12):1021–1027.

Sand, M., R. K. Berntsen, Ø Seland, and J. E. Kritjánsson. 2013. Arctic Surface Temperature Change to Emissions of Black Carbon within Arctic or Midlatitudes. J*ournal of Geophysical Research: Atmospheres* 118(14):7788–7798.

Sardar, A., and S. Mubashir. 2011. Plug-in Hybrids for Public Transport—Benefits and Impacts. SAE International. Paper No. 2011-28-0067.

SCBD (Secretariat of the Convention on Biological Diversity). 2009. Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. Montreal. Technical Series No. 46.

Schewe, J., J. Heinkea, D. Gerten, I. Haddeland, N. W. Arnell, D. B. Clark, R. Dankers, S. Eisner, B. M. Fekete, F. J. Colón-González, S. N. Gosling, H. Kim, X. Liu, Y. Masaki, F. T. Portmann, Y. Satoh, T. Stacke, Q. Tang, Y. Wada, D. Wisser, T. Albrecht, K. Frieler, F. Piontek, L. Warszawski, and P. Kabat. 2014. Multimodel Assessment of Water Scarcity under Climate Change. Proceedings of the National Academy of Sciences 111(9):3245–3250.

Schexnayder, S. M., S. Das, R. Dhingra, J. G. Overly, B. E. Tonn, J. H. Peretz, G. Waidley, and G. A. Davis. 2001. Environmental Evaluation of New Generation Vehicles and Vehicle Components. Report ORNL/TM-2001-266. Oak Ridge, TN: 133 pgs.

Schimel, D., J. Melillo, H. Tian, A. D. McGuire, D. Kicklighter, T. Kittel, N. Rosenbloom, S. Running, P. Thornton, D. Ojima, W. Parton, R. Kelly, M. Sykes, R. Neilson, and B. Rizzo. 2000. Contribution of

Increasing CO2 and Climate to Carbon Storage by Ecosystems in the United States. *Science* 287(5460):2004–2006.

Schimel, J. 2013. Soil Carbon: Microbes and Global Carbon. *Nature Climate Change* 3(10):867–868.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobied, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change. *Science* 319(5867):1238–1240.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang. 2012. Changes in Climate Extremes and their Impacts on the Natural Physical Environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press. Cambridge, UK, and New York, NY.

Shan, Z., S. Qin, Q. Liu, and F. Liu. 2012. Key Manufacturing Technology and Equipment for Energy Saving and Emissions Reduction in Mechanical Equipment Industry. *International Journal of Precision Engineering and Manufacturing* 13(7):1095–1100.

Sharpe, B., and M. Roeth. 2014. Costs and Adoption Rates of Fuel-Saving Technologies for Trailers in the North American On-Road Freight Sector. The International Council on Clean Transportation.

Shindell, D., and G. Faluvegi. 2009. Climate Response to Regional Radiative Forcing during the Twentieth Century. *Nature Geoscienc*e 2(4):294–300.

Shinnecock Indian Nation. 2013. Climate Change Adaptation Plan. PRiMO IKE Hui Technical Input for the National Climate Assessment – Tribal Chapter. PRiMO IKE Hui Meeting – January 2012, Hawaiʻi, 5 pp. K. Souza, and J. Tanimoto. Washington DC: U.S. Global Change Research Program.

Shukla, J. B., S. Sundar, Shivangi, and R. Nareshl. 2012. Modeling and Analysis of the Acid Rain Formation due to Precipitation and its Effect on Plant Species. *Natural Resource Modeling* 26(1):53–65.

Shurepower. 2007. Electric-Powered Trailer Refrigeration Unit Demonstration. Prepared for the New York State Energy Research and Development Authority (NYSERDA) and the U.S. EPA SmartWay Transport Partnership by Shurepower, LLC. Agreement No. 8485-3. December 20.

Silver Eagle. 2014. Silver Eagle Aero Saber. *Available at*: http://www.silvereaglemfg.com/aero/documents/Aero%20brochure%20Aero%20Saber.pdf. (Accessed: June 17, 2015).

Silver, J., C. McEwan, L. Petrella, and H. Bagulan. 2013. Climate Change, Urban Vulnerabilitiy and Development in Saint-Louis and Bobo-Dioulasso: Learning from Across Two West African Cities. Local Environment. *The International Journal of Justice and Sustainability* 18(6):663–677.

Silverman, D. T., Samanic, C. M., Lubin, J. H., Blair, A. E., Stewart, P. A., Vermeulen, R., & Attfield, M. D. (2012). The Diesel Exhaust in Miners Study: A Nested Case–Control Study of Lung Cancer and Diesel Exhaust. Journal of the National Cancer Institute.

Slipstreem Aerodynamics. 2014. Improve Trailer Aerodynamics & Start Saving Fuel. *Available at*: http://www.slipstreemaero.com/. (Accessed: June 17, 2015).

Smargiassi, A., T. Kosatsky, J. Hicks, C. Plante, B. Armstrong, P. J. Villeneuve, and S. Goudreau. 2009. Risk of Asthmatic Episodes in Children Exposed to Sulfur Dioxide Stack Emissions from a Refinery Point Source in Montreal, Canada. Environmental Health Perspective 117(4):653–659.

Smith, B. 2002. Statement of Senator Bob Smith, Environment & Public Works Committee Hearing on Transportation & Air Quality. 1d, 110 Session. July 30, 2002. *Available at*: http://epw.senate.gov/107th/smi_073002.htm. (Accessed: June 25, 2014).

Smith, K. R., and T.K. Takaro. 2012. An Official American Thoracic Society Workshop Report: Climate Change and Human Health. *Proceedings of the American Thoracic Society* 9:3–8.

Smith, S. J., and T. M. L. Wigley. 2006. Multi-Gas Forcing Stabilization with the MiniCAM. *Energy Journal* Special Issue 3:373–392.

Smithwick, E. A. H., A. L. Westerling, M. G. Turner, W. H. Romme, and M. G. Ryan. 2011. Vulnerability of Lnadscape Carbon Fluxes to Future Climate and Fire in the Greater Yellowstone Ecosystem. Temperature during egg formation and the effect of climate warming on egg size in a small songbird. In: Questioning Greater Yellowstone's Future: Climate, Land Use, and Invasive Species. Proceedings of the 10th Biennial Scientific Conference on the Greater Yellowstone Ecosystem. October 11–13, 2010, Mammoth Hot Springs Hotel, Yellowstone National Park. C. Andersen, ed., Pgs. 131–134. Yellowstone National Park, WY, and Laramie, WY, Yellowstone Center for Resources and University of Wyoming William D. Ruckelshaus Institute of Environment and Natural Resources.

Song, Y. S., J. R. Youn, and T. G. Gutowski. 2009. Life Cycle Energy Analysis of Fiber-Reinforced Composites. Composites: Part A 40A(8):1257–1265. *Available at*: http://web.mit.edu/ebm/www/Publications/JCOMA2464.pdf. (Accessed: July 2014).

Spracklen, D. V., K. S. Carslaw, U Pöschl, A. Rap, and P. M. Forster. 2011. Global Cloud Condensation Nuclei Influenced by Carbonaceous Combustion Aerosol. *Atmospheric Chemistry and Physics* 11(17):9067–9087.

SPRC (States for Passenger Rail Coalition). 2011. The 2011 Annual Report. *Available at*: http://www.s4prc.org/sites/default/files/reports/2011AnnualReportSPRC.pdf. (Accessed: June 17, 2015).

Spring, Ú. O. 2014. Social and Environmental Vulnerability in a River Basin of Mexico. In: Expanding Peace Ecology: Peace, Security, Sustainability, Equity and Gender, Springer, pgs. 85–109.

Stewart, B. C., K. E. Kunkel, L. E. Stevens, L. Sun, and J. E. Walsh. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 7. Climate of Alaska. NOAA Technical Report NESDIS 142-7.

Stewart, B. C., K. E. Kunkel, L. E. Stevens, L. Sun, and J. E. Walsh. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 7. Climate of Alaska. NOAA Technical Report NESDIS 142-7 **citing** Shulski, M., and G. Wendler. 2007. The Climate of Alaska. University of Alaska Press. Anchorage, AK.

Stockmann, U., M. A. Adams, J. W. Crawford, D. J. Field, N. Henakaarchchi, M. Jenkins, B. Minasny, A. B. McBratney, V. de Remy de Courcelles, K. Singh, I. Wheeler, L. Abbott, D. A. Angers, J. Baldock, M. Bird, P. C. Brookes, C. Chenu, J. D. Jastrow, R. Lal, J. Lehmann, A. G. O'Donnell, W. J. Parton, D.

Whitehead, and M. Zimmermann. 2013. The Knowns, Known Unknowns and Unknowns of Sequestration of Soil Organic Carbon. Agriculture. Ecosystems & Environment 164:80–99.

Stodolsky, F., A. Vyas, R. Cuenca, and L. Gaines. 1995. Life-Cycle Energy Savings Potential from Aluminum-Intensive Vehicles. Argonne National Laboratory. Conference Paper. 1995 Total Life Cycle Conference & Exposition. October 16–19, 1995. Vienna, Austria. *Available at*: http://www.transportation.anl.gov/pdfs/TA/106.pdf. (Accessed: July 2014).

Strehl. 2014. Trailer Blade. Proven Fuel Savings, *Available at*: http://www.strehlusa.com/main/Details/index.php. (Accessed: July 2014).

Striegel, M. F., E. B. Guin, K. Hallett, D. Sandoval, R. Swingle, K. Knox, F. Best, and S. Fornea. 2003. Air Pollution, Coatings, and Cultural Resources. *Progress in Organic Coatings* 48(2–4):281–288.

Sun, X., S. Zhang, and X. Ma. 2014. No Association Between Traffic Density and Risk of Childhood Leukemia: A meta-analysis. *Asia Pac J Cancer Prev* 15:5229–5232.

Surcel, M.D., and J. Michaelsen. 2010. Evaluation of Tractor-Trailer Rolling Resistance Reducing Measures. Paper SAE 2010-01-1917. SAE International.

Tarnocai, C., J. G. Canadell, E. A. G. Schuur, P. Kuhry, G. Mazhitova, and S. Zimov. 2009. Soil Organic Carbon Pools in the Northern Circumpolar Permafrost Region. Global Biogeochem. Cycles 23, GB2023.

Tebaldi, C., B. H. Strauss, and C. E. Zervas. 2012. Modelling Sea Level Rise Impacts on Storm Surges along US Coasts. *Environmental Research Letters* 7(1):014032.

Teixeira, E. I., G. Fischer, H. van Velthuizen, C. Walter, and F. Ewert. 2014. Global Hot-spots of Heat Stress on Agricultural Crops due to Climate Change. *Agricultural and Forest Meteorology* 170:206–215.

Tempelman, E. 2011. Multi-Parametric Study of the Effect of Materials Substitution on Life Cycle Energy Use and Waste Generation of Passenger Car Structures. *Transportation Research Part D* 16:479–485.

The Royal Society. 2005. Ocean Acidification due to Increasing Atmospheric Carbon Dioxide. Policy document 12/05, June 2005, The Royal Society, London.

Theebe, M. A. 2004. Planes, Trains, and Automobiles: The Impact of Traffic Noise on House Prices. The *Journal of Real Estate Finance and Economics* 28(2–3):209–234.

Thomson, A. M., K. V. Calvin, S. J. Smith, G. P. Kyle, A. Volke, P. Patel, S. Delgado Arias, B. Bond-Lamberty, M. A. Wise, L. E. Clarke, and J. A. Edmonds. 2011. RCP4. 5: A Pathway for Stabilization of Radiative Forcing by 2100. *Climatic Chang*e 109(1–2):77–94.

Thornton, P. K., P. J. Ericksen, M. Herrero, and A. J. Challinor. 2014. Climate Variability and Vulnerability to Climate Change: A Review. Global Change Biology.

Thornton, P. K., P. J. Ericksen, M. Herrero, and A. J. Challinor. 2014. Climate Variability and Vulnerability to Climate Change: A Review **citing** Mohammed, A. R., & Tarpley, L. 2009. High Nighttime Temperatures Affect Rice Productivity through Altered Pollen Germination and Spikelet Fertility. Agricultural and Forest Meteorology 149(6):999–1008. Global Change Biology.

Thornton, P. K., P. J. Ericksen, M. Herrero, and A. J. Challinor. 2014. Climate Variability and Vulnerability to Climate Change: A Review **citing** NRC. 1981. Effect of Environment on Nutrient Requirements of Domestic Animals. Subcommittee on Environmental Stress, National Academy Press, Washington DC. Global Change Biology.

Thornton, P. K., P. J. Ericksen, M. Herrero, and A. J. Challinor. 2014. Climate Variability and Vulnerability to Climate Change: A Review **citing** Baylis M, Githeko AK. 2006. The Effects of Climate Change on Infectious Diseases of Animals. Report for the Foresight Project on Detection of Infectious Diseases. Department of trade and industry UK government. Global Change Biology.

TIAX. 2009. Assessment of Fuel Economy Technologies for Medium- and Heavy- Duty Vehicles. Final Report to National Academy of Sciences. TIAX Case D0506.

Timm, O., and H. F. Diaz. 2009. Synoptic-Statistical Approach to Regional Downscaling of IPCC Twenty-First-Century Climate Projections: Seasonal Rainfall over the Hawaiian Islands. *Journal of Climate* 22(16):4261–4280.

Tobin, P.C., D. Parry, and B. H. Aukema. 2014. The Influence of Climate Change on Insect Invasions in Temperate Forest Ecosystems. Challenges and Opportunities for the World's Forests in the 21st Century. *Forestry Sciences* 81:267–293.

Todd, B. D., D. E. Scott, J. H. K. Pechmann, and J. W. Gibbons. 2011. Climate Change Correlates with Rapid Delays and Advancements in Reproductive Timing in An Amphibian Community. *Proceedings of the Royal Society Biological Sciences* 278:2191–2197.

Turtletaub, K. W., and C. Mani. 2003. Benzene Metabolism in Rodents at Doses Relevant to Human Exposure from Urban Air. Research Report 113. *Research Report Health Effects Institute* (113):1–46.

Tzanatos, E., D. E. Raitsos, G. Triantafyllou, S. Somarakis, and A. A. Tsonis. 2014. Indications of a Climate Change Effect on Mediterranean Fisheries. *Climate Change* 122(1–2):41–54.

Ugrekhelidze, D., F. Korte, and G. Kvesitadze. 1997. Uptake and Transformation of Benzene and Toluene by Plant Leaves. *Ecotoxicology and Environmental Safety* 37(1):24–29.

UN (United Nations Department of Economic and Social Affairs). 2011. Global Overview on Fuel Efficiency and Motor Vehicle Emission Standards: Policy Options and Perspectives for International Cooperation. United Nations Department of Economic and Social Affairs. Beijing, Los Angeles, New York.

UNEP (United Nations Environment Program) and WMO (World Meteorological Organization). 2011. Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers, UNEP (United Nations Environment Program) and WMO (World Meteorological Organization).

UNESCO (United National Educational, Scientific, and Cultural Organization). 2006. Water a Shared Responsibility: The United Nations World Water Development Report 2. Paris, France and New York, NY.

UNFCCC (United Nations Framework Convention on Climate Change). 2002. The United Nations Framework Convention on Climate Change. *Available at*: http://unfccc.int/essential_background/convention/items/2627.php. (Accessed: June 23, 2014).

UNFCCC. 2010. Press Release: UNFCCC Receives List of Government Climate Pledges. Last revised: February 1, 2010. *Available at*: http://unfccc.int/files/press/news_room/press_releases_and_advisories/application/pdf/pr_accord_100201.pdf. (Accessed: June 23, 2014).

UNFCCC. 2012. Report of the Conference of Parties on its Seventeenth Session, held in Durban from 28 November to 11 December 2011. Addendum: Part Two: Action taken by the Conference of the Parties at its seventeenth session.

UNFCCC. 2012. Report of the Conference of Parties on its Seventeenth Session. Last revised: March 15, 2012. *Available at*: http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf. (Accessed: June 23, 2014).

UNFCCC. 2014a. Kyoto Protocol. *Available at*: http://unfccc.int/kyoto_protocol/items/2830.php. (Accessed: June 20, 2014).

UNFCCC. 2014b. Durban: Towards Full Implementation of the UN Climate Change Convention. *Available at*: http://unfccc.int/key_steps/durban_outcomes/items/6825.php. (Accessed: June 20, 2014).

UNFCCC. 2014c. Warsaw Outcomes. *Available at*: https://unfccc.int/key_steps/warsaw_outcomes/items/8006.php. (Accessed: June 20, 2014).

Ungureanu, C.A., S. Das, and I. S. Jawahir. 2007. Life-Cycle Cost Analysis: Aluminum Versus Steel in Passenger Cars. Pgs. 11–24. In: Aluminum Alloys for Transportation, Packaging, Aerospace, and Other Applications. S.K. Das and W. Yin (Eds.). Orlando, Florida: TMS.

U.S. Bureau of Reclamation. 2011. Reclamation, Managing Water in the West: SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water. Report to Congress. Denver, CO, U.S. Department of the Interior, Policy and Administration, Bureau of Reclamation.

USACE (U.S. Army Corps of Engineers). 2009. Alaska Baseline Erosion Assessment. *Available at*: http://www.climatechange.alaska.gov/docs/iaw_USACE_erosion_rpt.pdf. (Accessed: June 10, 2014).

USACE. 2014. Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation. Draft. Technical Letter No. 1100-2-xx, U.S. Corps of Engineers.

USDA (U.S. Department of Agriculture). 2008. Agricultural Statistics 2008. *Available at*: http://www.nass.usda.gov/Publications/Ag_Statistics/2008/2008.pdf. (Accessed: June 3, 2014).

USDA. 2013. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935 **citing** Frank K.L. T.L. Mader J.A. Harrington, G.L. Han, and M.S. Davis, 2001. Climate Change Effects on Livestock Production in the Great Plains. St. Joseph, MI. Washington DC: U.S. Department of Agriculture.

USDA. 2013. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935 **citing** USDA (U.S. Department of Agriculture). 2008. The Synthesis and Assessment Product 4.3 (SAP 4.3): The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. Washington DC: U.S. Department of Agriculture.

U.S. Department of Energy. 2008. DOE Actively Engaged in Investigating the Role of Biofuels in Greenhouse Gas Emissions from Indirect Land Use Change. *Available at*: http://www1.eere.energy.gov/bioenergy/pdfs/obp_science_response_web.pdf. (Accessed: October 14, 2014).

U.S. Department of Energy. 2013. U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather. *Available at*: http://energy.gov/downloads/us-energy-sector-vulnerabilities-climate-change-and-extreme-weather. (Accessed: June 17, 2015).

U.S. Department of Energy. 2013a. Clean Cities Guide to Alternative Fuel and Advanced Medium- and Heavy-Duty Vehicles. DOE/GO-102013-3624.Prepared by the National Renewable Energy Laboratory (NREL), Office of Energy Efficiency and Renewable Energy.

U.S. Department of Energy. 2013b. Clean Cities Handbook for Handling, Storing, and Dispensing E85 and Other Ethanol-Gasoline Blends. U.S. Department of Energy. *Available at*: http://www.afdc.energy.gov/uploads/publication/ethanol_handbook.pdf. (Accessed: July 8, 2014).

U.S. Department of Energy. 2013c. Workshop Report: Trucks and Heavy-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials. Final Report, February 2013. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Vehicle Technologies Office. DOE/EE-0867.

U.S. Department of State – Stern, T. 2011. U.S. Statement at COP17: Special Envoy for Climate Change. *Available at*: http://www.state.gov/e/oes/rls/remarks/2011/178458.htm. (Accessed: April 12, 2012).

U.S. EIA (U.S. Energy Information Administration). 2014a. Natural Gas Prices Website. U.S. Energy Information Administration. *Available at*: http://www.eia.gov/naturalgas/reports.cfm?t=66. (Accessed: July 2014).

U.S. EIA. 2014b. How Much Carbon Dioxide is Produced when Different Fuels are Burned? Frequently Asked Questions Website. U.S. Energy Information Administration. *Available at*: http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11. (Accessed: June 4, 2014).

U.S. EIA. 2014c. Market Trends: Natural Gas. Annual Energy Outlook 2014. U.S. Energy Information Administration. *Available at*: http://www.eia.gov/forecasts/aeo/MT_naturalgas.cfm#natgas_prices?src=Natural-b1. (Accessed: June 4, 2014).

USFS (U.S. Forest Service). 2008. Beetle Epidemic: Introduction. *Available at*: http://www.fs.fed.us/gsearch/beetle%2Bepidemic. (Accessed: April 20, 2015).

USGS. 2015. California Water Science Center: The California Drought. *Available at*: http://ca.water.usgs.gov/data/drought/index.html. (Accessed: May 13, 2015).

U.S. House of Representatives Committee on Energy and Commerce. 2011. Chemicals Used in Hydraulic Fracturing. *Available at*: http://fas.org/sgp/crs/misc/R42461.pdf. (Accessed: July 8, 2014).

U.S. State Department. 2014. Final Supplemental Environmental Impact Statement for the Keystone XL Project. United States Department of State Bureau of Oceans and International Environmental and

Scientific Affairs. *Available at*: http://keystonepipeline-xl.state.gov/finalseis/. (Accessed: June 17, 2015).

Van Buskirk, J., R. S. Mulvihill, and R. C. Leberman. 2010. Declining Body Sizes in North American Birds Associated with Climate Change. *Oikos* 119(6):1047–1055.

Van Huijgevoort, M. H. J., P. Hazenberg, H. A. J. van Lanen, A. J. Teuling, D. B. Clark, S. Folwell, S. N. Gosling, N. Hanasaki, J. Heinke, S. Koirala, T. Stacke, F. Voss, J. Sheffield, and R. Uijlenhoet. 2013. Global Multi-model Analysis of Drought in Runoff for the Second Half of the Twentieth Century. *Journal of Hydrometeorology* 14:1535–1552.

Vanos, J., L. S. Kalkstein, and T. J. Sanford. 2014. Detecting Synoptic Warming Trends Across the US Midwest and Implications to Human Health and Heat-related Mortality. International Journal of Climatology.

Vaquer-Sunyer, R., and C. M. Duarte. 2011. Temperature Effects on Oxygen Thresholds for Hypoxia in Marine Benthic Organisms. *Global Change Biology* 17(5):1788–1797.

Verburg, P. H., E. Koomen, M. Hilferink, M. Pérez-Soba, and J. P. Lesschen. 2012. An Assessment of the Impact of Climate Adaptation Measures to Reduce Flood Risk on Ecosystem Services. *Landscape Ecology* 27(4):473–486.

Vidic, R., S. L. Brantley, J. M. Vandenbossche, D. Yoxtheimer, and J. D. Abad. 2013. Impact of Shale Gas Development on Regional Water Quality. *Science* 340(6134).

Vinyeta, K., and K. Lynn. 2013. USDA: Exploring the Role of Traditional Ecological Knowledge in Climate Change Initiatives **citing** U.S. Environmental Protection Agency (EPA). 2010. EPA Region 10 Action Plan from 2010 Tribal Leaders Summit. *Available at*: http://www.epa.gov/region10/pdf/tribal/2010_tribal_leaders_summit_action_plan.pdf. (Accessed: June 27, 2012).

Viskari, E.-L. 2000. Epicuticular Wax of Norway Spruce Needles as Indicator of Traffic Pollutant Deposition. *Water, Air, and Soil Pollution* 121(1):327–337.

Vitousek, P. M., T. N. Ladefoged, P. V. Kirch, A. S. Hartshorn, M. W. Graves, S. C. Hotchkiss, S. Tuljapurkar, and O. A. Chadwick. 2004. Soils, Agriculture, and Society in Precontact Hawaii. *Science* 304(5677):1665–1669.

Volk, H.E., Hertz-Picciotto, I., Delwiche, L., et al. 2011. Residential proximity to freeways and autism in the CHARGE study. *Environ Health Perspect* 119:873-877.

Volz, C.D., K. Ferrar, D. Michanowicz, C. Christen, S. Kearney, M. Kelso, and S. Malone. 2011. Contaminant Characterization of Effluent from Pennsylvania Brine Treatment Inc., Josephine Facility Being Released into Blacklick Creek, Indiana County, Pennsylvania. *Available at*: http://go.nature.com/5otd59. (Accessed: July 2014).

von Lampe, M., D. Willenbockel, H. Ahammad, E. Blanc, Y. Cai, K. Calvin, S. Fujimori, T. Hasegawa, P. Havlik, E. Heyhoe, P. Kyle, H. Lotze-Campen, D. M. d'Croz, G. C. N, R. D. Sands, C. Schmitz, A. Tabeau, H. Valin, D. van der Mensbrugghe, andHans van Meijl. 2014. Why Do Global Long-Term Scenarios for Agriculture Differ? An Overview of the AgMIP Global Economic Model Intercomparison. *Agricultural Economics* 45(1):3–20.

Vujičić, A., N. Zrnić, and B. Jerman. 2013. Ports Sustainability: A Life Cycle Assessment of Zero Emission Cargo Handling Equipment. Strojniški vestnik—J*ournal of Mechanical Engineering* 59(2013)9:547–555.

Wabash Composites. 2014. Trailer Side Skirts. *Available at*: http://www.wabashcomposites.com/products/trailer-side-skirts. (Accessed: July 2014).

Walthall, C., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E. A. Ainsworth, C. Ammann, C. J. Anderson, I. Bartomeus, L. H. Baumgard, F. Booker, B. Bradley, D. M. Blumenthal, J. Bunce, K. Burkey, S. M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D. A. Grantz, D. Goodrich, S. Hu, R. C. Izaurralde, R. A. C. Jones, S-H. Kim, A. D. B. Leaky, K. Lewers, T. L. Mader, A. McClung, J. Morgan, D. J. Muth, M. Nearing, D. M. Oosterhuis, D. Ort, C. Parmesan, W. T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W. A. Salas, L. E. Sollenberger, R. Srygley, C. Stöckle, E. S. Takle, D. Timlin, J. W. White, R. Winfree, L. Wright-Morton, and L. H. Ziska. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. Washington DC: U.S. Department of Agriculture.

Wang, M., M. Wu, and H. Huo. 2007. Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types. Environmental Research Letters 2 (2007) 024001. *Available at*: http://iopscience.iop.org/1748-9326/2/2/024001/pdf/erl7_2_024001.pdf. (Accessed: August 2014).

Wardle, D. A., R. D. Bardgett, J. N. Klironomos, H. Setälä, W. J. van der Putten, and D. H. Wall. 2004. Ecological Linkages Between Aboveground and Belowground Biota. *Science* 304(5677):1629–1633.

Weber-Tschopp, A., T. Fischer, R. Gierer, and E. Granjean. 1977. Experimentelle Reizwirkungen von Acrolein auf den Menschen (In German). *International Archives of Occupational Environmental Health* 40(2):117–130.

Weed, A. S., M. P. Ayres, and J. A. Hicke. 2013. Consequences of Climate Change for Biotic Disturbances in North American Forests. *Ecological Monographs* 83(4):441–470.

Weiss, J. L., J. T. Overpeck, and B. Strauss. 2011. Implications of Recent Sea Level Rise Science for Low-elevation Areas in Coastal Cities of the Conterminous USA. *Climatic Change* 105(3–4):635–645.

Weiss, M. A., J. B. Heywood, E. M. Drake, A. Schafer, and F. F. AuYeung. 2000. On the Road in 2020: A Lifecycle Analysis of New Automobile Technologies. Energy Laboratory Report # MIT EL 00-003. Cambridge, MA: Massachusetts Institute of Technology. *Available at*: http://web.mit.edu/energylab/www/pubs/el00-003.pdf. (Accessed: July 8, 2014).

Wenger, S. J., D. J. Isaak, C. H. Luce, H. M. Neville, K. D. Fausch, J. B. Dunham, D. C. Dauwalter, M. K. Young, M. M. Elsner, B. E. Rieman, A. F. Hamlet, and J. E. Williams. 2011. Flow Regime, Temperature, and Biotic Interactions Drive Differential Declines of Trout Species under Climate Change. *Proceedings of the National Academy of Sciences* 108(34):14175–14180.

Wentz, F. J., L. Ricciardulli, K. Hilburn, and C. Mears. 2007. How Much More Rain Will Global Warming Bring? *Science* 317(5835):233–235. doi: 10.1126/science.1140746.

Wenzel, T. 2014. The Effect of Recent Trends in Vehicle Design on US Societal Fatality Risk per Vehicle Mile Traveled, and Their Projected Future Relationship with Vehicle Mass. Lawrence Berkeley National Laboratory. *Accident Analysis & Prevention* 56:71–81.

Werrell, C., and F. Femia. 2012. The 3D Printing Revolution, Climate Change and National Security: An Opportunity for U.S. Leadership. The Center for Climate and Security.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and Earlier Spring Increase Western US Forest Wildfire Activity. *Science* 313(5789):940–943.

White House. 2014a. Improving the Fuel Efficiency of American Trucks–Bolstering Energy Security, Cutting Carbon Pollution, Saving Money and Supporting Manufacturing Innovation. *Available at*: https://www.whitehouse.gov/sites/default/files/docs/finaltrucksreport.pdf. (Accessed: May 26, 2014).

White House. 2014b. New Report: The All-of-the-Above Energy Strategy as a Path to Sustainable Economic Growth. Posted by Jason Furman, Jim Stock. May 29. *Available at*: http://www.whitehouse.gov/blog/2014/05/29/new-report-all-above-energy-strategy-path-sustainable-economic-growth. Accessed April 20, 2015.

Wieder, W. R., J. Boehnert, and G. B. Bonan. 2014. Evaluating Soil Biogeochemistry Parameterizations in Earth System Models with Observations. *Global Biogeochemical Cycles* 28(3):211–222.

Wigley, T., L. Clarke, J. Edmonds, H. Jacoby, S. Paltsev, H. Pitcher, J. Reilly, R. Richels, M. Sarofim, and S. Smith. 2009. Uncertainties in Climate Stabilization. *Climatic Change* 97(1–2):85–121.

Wigley, T. M. L. 2008. MAGICC 5.3.v2 User Manual. UCAR – Climate and Global Dynamics Division: Boulder, CO. *Available at*: http://www.cgd.ucar.edu/cas/wigley/magicc/UserMan5.3.v2.pdf. (Accessed: August 25, 2014).

Wilker, E. H., E. Mostofsky, S. H. Lue, D. Gold, J. Schwartz, G. A. Wellenius, and M. A. Mittleman. 2013. Residential Proximity to High-Traffic Roadways and Poststroke Mortality. *Journal of Stroke and Cerebrovascular Diseases* 22(8):e366–e372.

Williams, A. P., C.D. Allen, A.K. Macalady, D. Griffin, C.A. Woodhouse, D.M. Meko, T.W. Setnam, S.A. Rauscher, R. Seager, H.D. Grissino-Mayer, J.S. Dean, E.R. Cook, C. Gangodagamage, M. Cai, and N.G. McDowell. 2013. Temperature as a Potent Driver of Regional Forest Drought Stress and Tree Mortality. *Nature Climate Change* 3(3):292–297.

Wise, M., K. Calvin, A. Thomson, L. Clarke, B. Bond-Lamberty, R. Sands, S. J. Smith, A. Janetos, and J. Edmonds. 2009. Implications of Limiting CO_2 Concentrations for Land Use and Energy. *Science* 324(5931):1183–1186.

Witik, R. A., J. Payet, V. Michaud, C. Ludwig, and J. E. Manson. 2011. Assessing the Life Cycle Costs and Environmental Performance of Lightweight Materials in Automotive Applications. *Composites: Part A* 42:1694–1709.

WMO (World Meteorological Organization). 2011. Scientific Assessment of Ozone Depletion: 2010. World Meteorological Organization Global Ozone Research and Monitoring Project. Geneva, Switzerland, World Meteorological Organization.

Wormworth, J., and K. Mallon. 2010. Bird Species and Climate Change: The Global Status Report: A Synthesis of Current Scientific Understanding of Anthropogenic Climate Change Impacts on Global Bird Species Now, and Projected Future Effects. Published August 2010. Climate Risk Pty Limited (Australia), Level 1, 36 Lauderdale Avenue, Fairlight, NSW.

WRI (World Resources Institute). 2013. COP 19 Made Small Steps Forward, But We Need Bolder Leaps. *Available at*: http://www.wri.org/blog/2013/11/cop-19-made-small-steps-forward-we-need-bolder-leaps. (Accessed: June 2, 2014).

WRI. 2015. Climate Analysis Indicators Tool (CAIT) 2.0: WRI's Climate Data Explorer. *Available at*: http://cait2.wri.org. (Accessed: April 22, 2015).

WSJ (Wall Street Journal). 2014. Cummins-Peterbilt SuperTruck Achieves 10.7 MPG in Latest Test.

Wu, J., Wilhelm, M., Chung, J., et al. 2011. Comparing exposure assessment methods for traffic-related air pollution in and adverse pregnancy outcome study. Environ Res 111: 685-6692.

Wu, Y-J., T. Hayat, A. Clarens, and B. L. Smith. 2013. Climate Change Effects on Transportation Infrastructure: Scenario-Based Risk Analysis Using Geographic Information Systems. Transportation Research Board, Energy and Global Climate Change 2013.

Wuebbles, D., G. Meehl, K. Hayhoe, T. R. Karl, K. Kunkel, B. Santer, M. Wehner, B. Colle, E. M. Fischer, R. Fu, A. Goodman, E. Janssen, V. Kharin, H. Lee, W. Li, L. N. Long, S. C. Olsen, Z. Pan, A. Seth, J. Sheffield, and L. Sun. 2014. CMIP5 Climate Model Analyses: Climate Extremes in the United States. *Bulletin of the American Meteorological Society* 95(4):571–583.

Yeh, S., S. M. Jordaan, A. R. Brandt, M. R. Turetsky, S. Spatari, and D. W. Keith. 2010. Land Use Greenhouse Gas Emissions from Conventional Oil Production and Oil Sands. *Environmental Science & Technology* 44(22):8766–8772.

Zanobetti, A., P. H. Stone, F. E. Spelzer, J. D. Schwartz, B. A. Coull, H. H. Suh, B. D. Nearling, M. A. Mittleman, R. L. Verrier, and D. R. Gold. 2009. T-wave Alternans, Air Pollution and Traffic in High-Risk Subjects. *American Journal of Cardiology* 104:665–670.

Zemp, M., and W. Haeberli. 2007. Glaciers and Ice Caps. Section 6B. Global Outlook for Ice & Snow. United Nations Environment Programme.

Zhang, J., J. E. McCreanor, P. Cullinan, K. F. Chun, P. Ohman-Strickland, I-K. Han, L. Järup, and M. J. Nieuwenhuijsen. 2009. Health Effects of Real-World Exposure Diesel Exhaust in Persons with Asthma. Res Rep Health Effects Inst 138. *Available at*: http://pubs.healtheffects.org/view.php?id=297. (Accessed: April 20, 2015).

Zhang, X., F. W. Zwiers, G. C. Hegerl, F. H. Lambert, N. P. Gillett, S. Solomon, P. A. Stott, and T. Nozawa. 2007. Detection of Human Influence on Twentieth-Century Precipitation Trends. Nature 448(7152):461–465. doi: 10.1038/nature06025.

Zhao, H., A. Burke, and M. Miller. 2013. Analysis of Class 8 Truck Technologies for Their Fuel Savings and Economics. *Transportation Research Part D* 23(2013):55–63.

Zhou, Y., and J. I. Levy 2007. Factors Influencing the Spatial Extent of Mobile Source Air Pollution Impacts: A Meta-analysis. *BMC Public Health* 7(1):89.

Zhu, K., C. W. Woodall, S. Ghosh, A. E. Gelfand, and J. S. Clark. 2014. Dual Impacts of Climate Change: Forest Migration and Turnover through Life History. *Global Change Biology* 20(1):251–264.

Ziemkiewicz, P.F., J.D. Quaranta, A. Darnell, and R. Wise. 2013. Exposure Pathways Related to Shale Gas Development and Procedures for Reducing Environmental and Public Risk. *Journal of Natural Gas Science and Engineering* 16:77–84.

Ziska, L. H. 2014. Increasing Minimum Daily Temperatures Are Associated with Enhanced Pesticide Use in Cultivated Soybean along a Latitudinal Gradient in the Mid-Western United States. *PloS one* 9(6): e98516.

Zwolsman, G., D. Vanham, P. Fleming, C. Davis, A. Lovell, D. Nolasco, O. Thorne, R. de Sutter, B. Fülöp, P. Staufer, and Å. Johannesessen. 2010. Climate Change and the Water Industry – Practical Responses and Actions. Perspectives on water and climate change adaptation, International Water Association. Den Haag, Netherlands.

CHAPTER 12 INDEX

A

Acid rain, 4-8, 7-2, 7-4, 7-6
Acidification, 4-8, 5-26, 5-101, 5-102, 5-104, 5-203, 5-208, 5-209, 5-211, 6-2, 6-20, 6-29, 7-3
Acidity, 5-104, 5-190, 5-199, 5-207, 5-209
Action alternatives, 1-3, 1-19, 2-1, 2-2, 2-4, 2-5, 2-12, 2-20, 2-22, 2-24, 2-26, 2-28, 2-30, 2-32, 3-13, 3-14, 3-15, 4-2, 4-15, 4-35, 4-41, 4-42, 4-44, 4-47, 4-51, 4-53, 4-54, 4-55, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-67, 4-70, 4-72, 4-79, 4-80, 4-81, 4-82, 4-83, 4-84, 4-85, 4-86, 5-1, 5-12, 5-27, 5-33, 5-36, 5-37, 5-41, 5-44, 5-45, 5-46, 5-47, 5-48, 5-51, 5-53, 5-56, 5-58, 5-61, 5-63, 5-65, 5-66, 5-70, 5-73, 5-75, 5-76, 5-80, 5-82, 5-86, 5-87, 5-208, 7-6, 7-8, 7-9, 7-11, 7-12, 7-13, 8-1, 8-2, 8-5
Adaptation, 5-21, 5-32, 5-40, 5-87, 5-89, 5-94, 5-100, 5-101, 5-106, 5-107, 5-115, 5-116, 5-126, 5-129, 5-133, 5-137, 5-141, 5-143, 5-145, 5-146, 5-158, 5-162, 5-171, 5-205
aerosols, 5-7, 5-15, 5-16, 5-18, 5-34
Agriculture, 2-26, 5-9, 5-16, 5-20, 5-90, 5-107, 5-108, 5-116, 5-127, 5-128, 5-129, 5-168, 5-170, 5-174, 5-177, 5-180, 5-181, 5-184, 5-189, 5-197, 5-200, 5-202, 5-203, 5-216, 6-10
Air pollutants, 2-23, 2-24, 2-29, 2-33, 4-1, 4-2, 4-4, 4-5, 4-6, 4-18, 4-19, 4-27, 4-29, 4-42, 4-44, 4-47, 4-56, 4-57, 4-58, 4-59, 4-60, 4-70, 4-71, 4-72, 4-82, 4-83, 4-84, 4-85, 4-86, 5-176, 5-214, 6-13, 6-14, 6-15, 7-2, 7-3, 7-11, 7-12, 8-1, 8-5
Air quality, 1-13, 1-17, 1-20, 2-23, 2-26, 2-27, 2-28, 2-29, 2-30, 2-32, 2-33, 4-1, 4-2, 4-6, 4-15, 4-16, 4-17, 4-18, 4-26, 4-27, 4-32, 4-33, 4-35, 4-61, 5-125, 5-126, 5-133, 5-134, 5-137, 5-163, 5-170, 5-176, 5-186, 6-1, 6-3, 6-5, 7-1, 7-2, 7-6, 7-10, 7-11, 7-12, 8-1, 8-2
Algae, 5-94, 5-98, 5-105, 5-129, 5-174, 5-190, 5-203, 5-211, 6-15
Alternative 1, 2-1, 2-2, 2-4, 2-5, 2-8, 2-9, 2-12, 2-14, 2-15, 3-14, 4-1, 4-41, 4-45, 4-56, 4-67, 4-71, 4-82, 5-1, 7-5, 8-1
Alternative 2, 2-3, 2-5, 2-6, 2-9, 2-12, 2-13, 2-15, 2-16, 3-15, 4-1, 4-38, 4-41, 4-47, 4-54, 4-55, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-62, 4-67, 4-72, 4-80, 4-81, 4-83, 4-84, 4-85, 4-86, 4-87, 5-41, 5-48, 5-53, 5-57, 5-65, 5-69, 5-76
Alternative 3, 2-2, 2-3, 2-6, 2-7, 2-9, 2-10, 2-13, 2-16, 2-17, 2-21, 2-27, 3-15, 4-1, 4-58, 4-67, 4-84, 5-35
Alternative 4, 2-3, 2-7, 2-10, 2-11, 2-13, 2-18, 4-1, 4-38, 4-41, 4-57, 4-58, 4-59, 4-60, 4-61, 4-67, 4-83, 4-84, 4-85, 4-86, 4-87
Alternative 5, 2-3, 2-7, 2-8, 2-11, 2-13, 2-14, 2-19, 3-15, 4-1, 4-38, 4-41, 4-45, 4-47, 4-54, 4-55, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-67, 4-71, 4-72, 4-80, 4-81, 4-82, 4-83, 4-84, 4-85, 4-86, 4-87, 5-45, 5-48, 5-53, 5-57, 5-65, 5-66, 5-69, 5-73, 5-75, 5-76, 5-82
Alternatives, 2-1, 2-2, 2-20, 2-27, 3-16, 4-35, 4-44, 4-53, 4-55, 4-61, 4-62, 4-70, 4-79, 4-81, 5-1, 5-47, 5-54, 5-57, 5-76
  Action, 1-3, 1-19, 2-1, 2-2, 2-4, 2-5, 2-12, 2-20, 2-22, 2-24, 2-26, 2-28, 2-30, 2-32, 3-13, 3-14, 3-15, 4-2, 4-15, 4-35, 4-41, 4-42, 4-44, 4-47, 4-51, 4-53, 4-54, 4-55, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-67, 4-70, 4-72, 4-79, 4-80, 4-81, 4-82, 4-83, 4-84, 4-85, 4-86, 5-1, 5-12, 5-27, 5-33, 5-36, 5-37, 5-41, 5-44, 5-45, 5-46, 5-47, 5-48, 5-51, 5-53, 5-56, 5-58, 5-61, 5-63, 5-65, 5-66, 5-70, 5-73, 5-75, 5-76, 5-80, 5-82, 5-86, 5-87, 5-208, 7-6, 7-8, 7-9, 7-11, 7-12, 7-13, 8-1, 8-2, 8-5
  Analyzed in the EIS, 2-1
  No Action, 1-19, 2-1, 2-2, 2-4, 2-5, 2-8, 2-12, 2-14, 2-20, 2-22, 2-24, 2-25, 2-28, 2-29, 2-30, 2-31, 2-31, 2-32, 2-33, 2-34, 2-35, 3-14, 3-15, 4-1, 4-2, 4-17, 4-35, 4-38, 4-41, 4-42, 4-43, 4-47, 4-51, 4-52, 4-54, 4-55, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-62, 4-67, 4-68, 4-69, 4-70, 4-72, 4-77, 4-78, 4-80, 4-81, 4-82, 4-83, 4-84, 4-85, 4-86, 4-87, 5-1, 5-12, 5-19, 5-27, 5-29, 5-33, 5-35, 5-36, 5-41, 5-42, 5-44, 5-45, 5-46, 5-47, 5-48, 5-49, 5-51, 5-53, 5-54, 5-55, 5-56, 5-57, 5-61, 5-62, 5-65, 5-66, 5-68, 5-69, 5-70, 5-71, 5-75, 5-76, 5-78, 5-79, 5-80, 5-82, 5-83, 5-84, 5-85, 5-86, 5-87, 7-5, 7-6, 7-8, 7-9, 7-12, 7-13, 8-1, 8-2, 8-5
Amazon rainforest, 5-136, 5-137
Annual Energy Outlook (AEO), 2-24, 2-25, 2-26, 3-1, 3-2, 3-4, 3-5, 3-8, 3-16, 6-5, 6-6, 6-8, 6-12, 8-3
Anthropogenic, 5-7, 5-8, 5-9, 5-14, 5-17, 5-19, 5-20, 5-22, 5-36, 5-60, 5-65, 5-73, 5-83, 5-92, 5-

100, 5-101, 5-129, 5-152, 5-154, 5-168, 5-181, 5-184, 5-209, 6-10
Aquaculture, 5-104, 5-168
Arctic sea ice, 5-144, 5-150, 5-152, 5-155, 5-159, 5-195
Assumptions. See Methodologies and assumptions
Atlantic Meridional Overturning Circulation (AMOC), 5-150, 5-151, 5-155
Atmospheric-ocean general circulation model (AOGCM), 5-200
Auxiliary power unit (APU), 2-2, 6-28, 6-29, 6-30, 6-31, 7-4
Averaging, banking, and trading (ABT), 1-10, 1-11, 1-12

B

Benthic, 5-90, 7-4
Biofuel, 3-8, 5-18, 5-39, 5-121, 5-132, 6-6, 6-16, 8-3
Biological resources, 7-2
Biosphere, 5-42
Black carbon, 5-15, 5-17, 5-19
Boreal forest, 5-155

C

California Air Resources Board (CARB), 1-4, 1-6, 1-19, 1-20, 5-37, 5-50, 5-51, 6-25, 7-5
Cap-and-trade, 5-37, 5-50
Carbon dioxide, 1-3, 1-4, 2-26, 2-31, 2-35, 4-6, 5-9, 5-47, 5-48, 5-51, 5-72, 5-209, 6-3, 8-3
Carbon sink, 5-99, 5-100, 5-114
Centers for Disease Control and Prevention (CDC), 4-5
Class 2, 1-8, 6-4, 7-2, 7-8
Class 2b, 1-8, 6-4, 7-2, 7-8
Class 3, 1-8
Class 4, 1-8
Class 5, 1-8, 6-5, 6-27
Class 6, 1-8
Class 7, 1-8, 2-9, 2-10, 2-11, 2-12, 7-8
Class 8, 1-8, 1-22, 2-4, 2-8, 2-9, 2-10, 2-11, 2-12, 2-14, 2-15, 2-16, 2-17, 2-18, 2-19, 6-5, 6-8, 6-22, 6-27, 6-28, 7-2, 7-7, 8-4
Clean Air Act (CAA), 1-5, 4-1, 4-2, 4-3, 4-13, 4-15, 4-26, 4-35, 5-2, 5-22, 5-38, 5-39, 5-50, 5-51, 8-2, 8-3
Clean Cities Program, 8-4
Climate analysis, 5-29, 5-68
Climate change, 5-93, 5-94, 5-96, 5-101, 5-107, 5-108, 5-109, 5-111, 5-112, 5-115, 5-117, 5-121, 5-122, 5-126, 5-127, 5-128, 5-134, 5-135, 5-136, 5-137, 5-138, 5-140, 5-142, 5-145, 5-147, 5-154, 5-158, 5-161, 5-162, 5-163, 5-164, 5-170, 5-174, 5-184, 5-189, 5-202, 5-203, 5-204, 5-205, 5-206, 5-207, 7-10
Abrupt, 5-42, 5-150, 5-152, 5-155
Causes, 5-5
Evidence of, 5-11
Trend, 5-160, 5-166, 5-173, 5-178, 5-182, 5-188, 5-195, 5-196, 5-201
Climate change indicators, 5-40, 5-41
Cumulative impacts on, 5-44
Climate Change Science Program (CCSP), 5-2, 5-15, 5-28, 5-34, 5-35, 5-103, 5-147, 5-166, 5-168, 5-169, 5-180, 5-198
Climate models, strengths and limitations, 5-3, 5-28, 5-58, 5-60, 5-64, 5-76, 5-91, 5-120, 5-128, 5-150, 5-165, 5-172, 5-187, 5-188, 5-190
Climate science, 5-42, 8-5
Climate sensitivity, 5-28, 5-30, 5-31, 5-33, 5-41, 5-42, 5-52, 5-68, 5-83, 5-86
Climate system, 5-1, 5-3, 5-7, 5-21, 5-27, 5-28, 5-32, 5-36, 5-41, 5-42, 5-99, 5-156, 5-211
Climate variability, 5-111, 5-127, 5-133, 5-140, 5-143, 5-144, 5-158, 5-182, 5-201, 5-202, 7-11
Climatic conditions, 5-5, 5-111, 5-140, 5-144, 5-192
CO_2 emissions, 1-4, 1-9, 1-21, 2-6, 2-22, 2-27, 3-1, 5-9, 5-15, 5-20, 5-21, 5-27, 5-29, 5-30, 5-31, 5-35, 5-36, 5-38, 5-39, 5-40, 5-44, 5-45, 5-46, 5-47, 5-48, 5-49, 5-50, 5-51, 5-68, 5-69, 5-70, 5-71, 5-73, 5-83, 5-101, 5-148, 5-154, 5-157, 5-158, 5-208, 5-211, 5-212, 5-216, 6-4, 6-7, 6-15, 6-16, 6-28, 6-29, 8-1, 8-4, 8-5
Coal, U.S. production, consumption, and export, 3-4
Coastal, 5-1, 5-24, 5-26, 5-28, 5-88, 5-91, 5-93, 5-94, 5-100, 5-101, 5-102, 5-103, 5-104, 5-106, 5-112, 5-117, 5-118, 5-119, 5-121, 5-123, 5-125, 5-131, 5-132, 5-140, 5-141, 5-143, 5-145, 5-158, 5-159, 5-160, 5-161, 5-162, 5-163, 5-165, 5-167, 5-168, 5-169, 5-171, 5-182, 5-183, 5-186, 5-188, 5-190, 5-192, 5-194, 5-196, 5-198, 5-199, 5-200, 5-201, 5-202, 5-203, 5-204, 5-205, 5-206, 5-207, 5-211, 6-27, 7-11
Code of Federal Regulations (CFR), 1-1, 1-3, 1-7, 1-13, 1-14, 1-17, 1-25, 2-1, 2-22, 2-27, 2-28, 2-32, 4-3, 4-15, 4-16, 4-19, 4-26, 7-2, 7-5, 7-6, 7-7, 8-1
Commercial Aviation Alternative Fuels Initiative (CAAFI), 8-4
Consumption, 1-1, 1-2, 1-4, 1-6, 1-7, 1-8, 1-9, 1-15, 2-3, 2-5, 2-6, 2-7, 2-8, 2-12, 2-20, 2-21, 2-23, 2-

24, 2-27, 3-1, 3-2, 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9, 3-10, 3-12, 3-13, 3-14, 3-15, 3-16, 4-17, 4-38, 4-62, 5-16, 5-21, 5-29, 5-44, 5-48, 5-73, 5-94, 5-146, 5-148, 5-169, 5-186, 5-208, 6-4, 6-5, 6-6, 6-7, 6-10, 6-11, 6-17, 6-19, 6-22, 6-23, 6-28, 6-29, 7-5, 7-10, 7-11, 7-12, 7-13, 8-2, 8-3, 8-4, 8-6
cooperating agency, 1-13
Corporate Average Fuel Economy (CAFE), 1-1, 1-2, 1-6, 1-7, 1-8, 2-20, 2-23, 2-24, 2-25, 3-10, 4-17, 4-26, 4-33, 5-2, 5-29, 5-35, 5-38, 5-158, 6-4, 7-1, 7-8, 8-3
Cost savings, 1-4, 1-19
Costs and benefits, 1-19, 1-22, 1-23, 4-16, 7-13
Council on Environmental Quality (CEQ), 1-3, 1-17, 1-25, 2-1, 2-22, 2-27, 2-32, 4-19, 5-1, 5-2, 5-87, 7-9, 8-1, 8-5
NEPA implementing regulations, 1-3, 1-17, 2-1, 2-22, 2-27, 2-32, 4-19, 5-2, 8-1
Criteria pollutants, 1-5, 2-23, 2-24, 2-29, 2-33, 4-1, 4-2, 4-3, 4-6, 4-16, 4-17, 4-18, 4-19, 4-27, 4-35, 4-38, 4-41, 4-42, 4-44, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-65, 4-67, 4-70, 4-71, 4-82, 4-83, 4-84, 4-85, 4-86, 8-2
Crude oil, 3-1, 3-3, 3-4, 3-5, 3-11, 3-13, 4-8, 4-26, 4-27, 5-29, 6-1, 6-2, 6-7, 7-3, 7-13
Cruising speed, 2-8, 6-27
Cryosphere, 5-42
Cumulative impacts, 1-18, 1-20, 2-2, 2-22, 2-27, 2-32, 3-1, 3-15, 4-1, 4-33, 4-35, 4-61, 5-1, 5-27, 5-35, 5-36, 5-37, 5-41, 5-42, 5-43, 5-44, 5-68, 5-70, 5-73, 5-75, 5-82, 5-87, 5-158, 5-207, 5-208

D

Developing economies, 5-73
Diesel, 1-2, 1-9, 1-12, 1-19, 1-21, 2-4, 2-5, 2-6, 2-7, 2-8, 2-14, 2-15, 2-16, 2-18, 2-19, 2-20, 2-21, 2-23, 2-24, 2-25, 2-29, 2-31, 2-33, 2-35, 3-4, 3-9, 3-10, 3-11, 3-14, 3-15, 3-16, 4-4, 4-7, 4-10, 4-11, 4-12, 4-14, 4-26, 4-33, 4-41, 4-45, 4-50, 4-51, 4-53, 4-67, 4-71, 4-75, 4-77, 4-79, 5-15, 5-16, 5-19, 5-29, 6-1, 6-4, 6-5, 6-6, 6-7, 6-8, 6-9, 6-10, 6-14, 6-15, 6-25, 6-26, 6-27, 6-28, 6-29, 6-30, 7-10, 7-12, 8-3
Diesel particulate matter, 2-31, 2-35, 4-4, 4-11, 4-45, 4-50, 4-51, 4-53, 4-71, 4-75, 4-77, 4-79
Direct impacts, 5-111, 5-121, 5-133, 5-154
Discount rate, 2-30, 2-34, 4-30, 4-32, 4-54, 4-55, 4-58, 4-59, 4-60, 4-61, 4-80, 4-81, 4-83, 4-85, 4-86, 4-87, 5-30, 5-31, 5-32, 5-51, 5-73
Diseases, 4-1, 4-7, 4-28, 5-107, 5-109, 5-110, 5-111, 5-114, 5-120, 5-130, 5-133, 5-135, 5-136, 5-164, 5-176, 5-197, 5-207
Vector-borne, 5-133, 5-135, 5-136, 5-164, 5-176, 7-10
Water- and food-borne, 5-133, 5-135
Downstream emissions, 2-23, 2-24, 2-25, 4-17, 4-35, 4-44, 4-61, 4-71, 6-26
Drive cycle, 1-13, 2-2, 2-3, 2-8, 2-20, 6-24, 6-26
Driver behavior, 4-16, 6-8
Drought, 5-23, 5-25, 5-90, 5-92, 5-93, 5-98, 5-102, 5-107, 5-108, 5-111, 5-113, 5-114, 5-117, 5-120, 5-121, 5-122, 5-127, 5-128, 5-132, 5-140, 5-142, 5-143, 5-144, 5-156, 5-158, 5-161, 5-166, 5-167, 5-168, 5-169, 5-170, 5-180, 5-182, 5-185, 5-202, 5-207, 5-215, 5-216

E

E85, 2-25, 2-26, 2-29, 2-31, 2-33, 2-35, 3-14, 3-16, 6-6, 6-16
Earth, 5-3, 5-5, 5-6, 5-7, 5-11, 5-14, 5-15, 5-17, 5-33, 5-41, 5-86, 5-87, 5-89, 5-100, 5-105, 5-146, 5-147, 5-148, 5-150, 5-156, 5-157, 5-206, 5-209, 7-12
Economic development, 5-102
Ecosystem, 5-30, 5-96, 5-97, 5-98, 5-99, 5-100, 5-105, 5-106, 5-107, 5-125, 5-126, 5-154, 5-174, 5-202, 5-208, 5-211, 5-216, 7-3
Emissions, 1-2, 1-5, 1-6, 1-7, 1-22, 2-2, 2-20, 2-23, 2-24, 2-25, 2-26, 2-29, 2-33, 4-13, 4-17, 4-18, 4-19, 4-20, 4-26, 4-31, 4-32, 4-34, 4-36, 4-37, 4-38, 4-39, 4-40, 4-42, 4-43, 4-44, 4-45, 4-46, 4-47, 4-48, 4-49, 4-51, 4-52, 4-53, 4-54, 4-55, 4-56, 4-58, 4-60, 4-61, 4-62, 4-63, 4-64, 4-65, 4-68, 4-69, 4-70, 4-71, 4-72, 4-73, 4-74, 4-75, 4-77, 4-78, 4-79, 4-80, 4-81, 4-82, 4-84, 4-86, 5-1, 5-9, 5-12, 5-16, 5-17, 5-19, 5-20, 5-29, 5-30, 5-34, 5-37, 5-38, 5-39, 5-40, 5-44, 5-45, 5-46, 5-47, 5-48, 5-50, 5-51, 5-52, 5-61, 5-68, 5-69, 5-70, 5-71, 5-73, 5-74, 5-83, 5-147, 5-154, 5-209, 6-3, 6-8, 6-11, 6-27, 7-1, 7-10, 8-1, 8-3, 8-4, 8-5
Downstream, 2-23, 2-24, 2-25, 4-17, 4-35, 4-44, 4-61, 4-71, 6-26
Estimates, 2-25, 2-26, 5-14
Sources, 4-4, 4-14, 4-31, 4-34, 5-8, 5-27, 5-37, 5-38, 5-98, 5-160, 5-167, 5-173, 5-183, 5-188, 5-196, 5-201, 6-10, 6-24, 8-4
Upstream, 1-23, 2-23, 2-24, 2-25, 4-17, 4-26, 4-27, 4-29, 4-41, 4-47, 4-57, 4-58, 4-59, 4-60, 4-67, 4-72, 4-83, 4-84, 4-85, 4-86, 5-29, 5-30, 5-

33, 5-35, 5-49, 6-1, 6-2, 6-3, 6-5, 6-6, 6-7, 6-29, 6-30, 7-11
Global, 2-26, 2-30, 2-34, 2-35, 5-5, 5-14, 5-20, 5-22, 5-23, 5-24, 5-25, 5-28, 5-34, 5-35, 5-36, 5-37, 5-41, 5-50, 5-52, 5-54, 5-56, 5-61, 5-62, 5-66, 5-76, 5-78, 5-79, 5-80, 5-82, 5-83, 5-85, 5-89, 5-97, 5-112, 5-160, 5-180, 5-188, 5-209
Energy, 1-1, 1-2, 1-3, 1-17, 2-1, 2-23, 2-24, 2-25, 2-26, 2-29, 2-33, 3-1, 3-2, 3-3, 3-6, 3-10, 3-11, 3-13, 3-17, 4-16, 4-17, 5-38, 5-39, 5-121, 5-122, 6-3, 6-5, 6-7, 6-14, 6-15, 6-25, 6-30, 7-1, 7-10, 8-4, 8-5
Energy consumption, 3-6, 8-5
Increase in, 3-2
Transportation sector, 1-1, 3-6, 3-8, 4-2, 5-9, 5-16, 5-27, 5-46, 5-73, 5-131, 6-11, 6-18, 7-3, 8-1, 8-2, 8-4
Energy imports, 3-1, 3-3, 3-6, 3-8, 3-10, 3-17
Energy Independence and Security Act (EISA), 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-6, 1-7, 1-16, 1-18, 1-22, 2-1, 2-23, 5-38
Energy Information Administration (EIA), 2-24, 3-1, 3-2, 3-3, 3-4, 3-5, 3-6, 3-8, 4-14, 4-27, 5-171, 6-5, 6-6, 6-11, 6-12, 8-3
Energy intensity, 3-1, 3-2, 8-1
Energy Policy and Conservation Act (EPCA), 1-1, 1-3, 2-1, 5-38
Engine manufacturers, 1-20, 2-4, 2-6, 6-15
Environmental impacts, 2-22, 2-28, 2-32, 2-33, 3-14, 3-15, 4-29, 4-33, 4-35, 4-36, 4-37, 4-39, 4-40, 4-43, 4-44, 4-45, 4-46, 4-48, 4-49, 4-52, 4-53, 4-61, 4-62, 4-63, 4-64, 4-65, 4-69, 4-70, 4-71, 4-73, 4-74, 4-75, 4-78, 4-79, 5-12, 5-17, 5-21, 5-35, 5-36, 5-37, 5-42, 5-44, 5-50, 5-52, 5-58, 5-68, 5-75, 5-83, 5-85, 5-86, 5-87, 5-90, 5-96, 5-101, 5-107, 5-117, 5-127, 5-131, 5-133, 5-136, 5-139, 5-140, 5-146, 5-150, 5-155, 5-158, 5-162, 5-204, 5-207, 5-211, 6-12, 7-1, 7-8, 7-12, 8-1
Unavoidable adverse, 7-12
Environmental justice, 7-1, 7-9
Environmental Protection Agency (EPA), 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 1-9, 1-12, 1-13, 1-14, 1-16, 1-17, 1-18, 1-19, 1-20, 1-22, 1-24, 1-25, 2-1, 2-2, 2-3, 2-4, 2-8, 2-12, 2-14, 2-20, 2-23, 2-24, 2-25, 2-26, 4-1, 4-2, 4-3, 4-4, 4-6, 4-7, 4-8, 4-9, 4-10, 4-11, 4-12, 4-13, 4-14, 4-15, 4-17, 4-19, 4-20, 4-26, 4-27, 4-28, 4-29, 4-30, 4-31, 4-32, 4-33, 4-34, 4-35, 4-38, 4-47, 4-53, 4-56, 4-61, 4-62, 4-72, 4-79, 4-82, 5-2, 5-9, 5-10, 5-16, 5-17, 5-19, 5-20, 5-21, 5-22, 5-23, 5-24, 5-25, 5-26, 5-28, 5-29, 5-30, 5-31, 5-32, 5-35, 5-37, 5-38, 5-39, 5-42, 5-50, 5-51, 5-61, 5-65, 5-73, 5-102, 5-114, 5-137, 5-157, 5-159, 5-161, 5-162, 5-165, 5-168, 5-169, 5-172, 5-173, 5-174, 5-175, 5-176, 5-177, 5-179, 5-181, 5-182, 5-184, 5-200, 5-201, 5-202, 5-205, 5-209, 5-213, 5-214, 6-3, 6-7, 6-8, 6-9, 6-10, 6-11, 6-15, 6-16, 6-25, 6-28, 7-1, 7-2, 7-3, 7-4, 7-5, 7-6, 7-8, 7-11, 8-1, 8-2, 8-3, 8-4
Cooperating agency, 1-13
Proposed GHG emissions standards, 1-4, 1-5, 1-6, 1-8, 1-12, 1-13, 1-23, 1-25, 2-1, 2-2, 2-12, 5-35, 5-38, 7-8, 8-3
Erosion, 5-24, 5-26, 5-101, 5-102, 5-103, 5-104, 5-109, 5-123, 5-129, 5-131, 5-132, 5-138, 5-140, 5-143, 5-145, 5-154, 5-164, 5-166, 5-169, 5-182, 5-190, 5-198, 5-199, 5-200, 5-203, 5-204, 5-206
Executive Order (EO) 13514, 5-87, 8-5

F

Federal Highway Administration (FHWA), 1-16, 4-4, 4-15, 4-20, 7-7, 8-2
Federal Motor Carrier Safety Administration (FMCSA), 1-13, 1-21
Federal Register (FR), 1-2, 1-4, 1-6, 1-7, 1-14, 2-1, 4-4, 4-6, 4-7, 4-8, 4-13, 4-14, 4-16, 5-38, 7-9, 8-3, 8-4
federal test procedure (FTP), 2-4, 2-5, 2-6, 2-7, 2-8, 2-20
Federal Transit Administration (FTA), 4-15, 8-2
Feedstock recovery, 4-26, 4-27
Fertilization, 5-98, 5-174, 5-208, 5-214
Final Regulatory Impact Analysis (FRIA), 7-8
Fisheries, effects of climate change, 5-88, 5-96, 5-101, 5-103, 5-104, 5-111, 5-112, 5-113, 5-127, 5-128, 5-130, 5-131, 5-140, 5-161, 5-197, 5-199, 5-200, 5-203
Flood, 5-90, 5-92, 5-93, 5-94, 5-101, 5-106, 5-140, 5-160, 5-162, 5-163, 5-179, 5-182, 5-187, 5-190
Food, fiber, and forest products, effects of climate change, 5-88, 5-160, 5-167, 5-173, 5-178, 5-183, 5-188, 5-196, 5-201
Food production, 5-108, 5-115, 5-168, 5-189, 5-211
Forest ecosystems, 5-100, 5-189, 5-208, 7-4
Forest products, 5-107, 5-116, 5-158, 5-164, 5-192, 5-204
Fossil fuels, 4-1, 4-17, 5-9, 5-12, 5-15, 5-20, 5-21, 5-35, 5-36, 5-73, 5-212, 6-2, 6-11, 7-6
freshwater resources, 5-1, 5-89, 5-90, 5-93, 5-94, 5-98, 5-158, 5-160, 5-164, 5-168, 5-177, 5-179,

5-184, 5-189, 5-192, 5-197, 5-200, 5-202, 5-204, 5-205
Effects of climate change, recent findings, 5-89, 5-96, 5-100, 5-133, 5-138
Fuel consumption, 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, 1-8, 1-9, 1-10, 1-11, 1-12, 1-13, 1-15, 1-16, 1-19, 2-1, 2-2, 2-3, 2-5, 2-6, 2-7, 2-8, 2-9, 2-12, 2-13, 2-14, 2-20, 2-22, 2-23, 2-25, 2-27, 2-29, 2-33, 3-1, 3-3, 3-6, 3-7, 3-8, 3-9, 3-10, 3-13, 3-14, 3-15, 3-16, 4-17, 4-38, 4-41, 4-62, 4-67, 5-1, 5-16, 5-29, 5-30, 5-47, 5-48, 5-68, 5-71, 5-73, 6-18, 6-22, 6-23, 6-25, 6-26, 6-30, 7-1, 7-3, 8-1, 8-2, 8-4
Fuel economy, 1-1, 1-2, 1-3, 1-6, 1-16, 1-21, 2-20, 2-23, 2-25, 3-8, 5-38, 5-40, 5-47, 5-48, 5-51, 6-2, 6-20, 6-21, 6-22, 6-25, 6-30, 8-4

G

Gasoline, 1-2, 1-7, 1-12, 1-19, 1-21, 2-4, 2-5, 2-14, 2-15, 2-16, 2-17, 2-18, 2-19, 2-21, 2-23, 2-24, 2-25, 2-26, 2-31, 2-35, 3-4, 3-8, 3-9, 3-10, 3-11, 3-12, 3-14, 3-16, 4-2, 4-7, 4-8, 4-13, 4-15, 4-26, 4-41, 4-67, 5-16, 5-19, 5-29, 5-39, 6-1, 6-5, 6-6, 6-7, 6-15, 6-16, 6-27, 7-3, 8-3
General Conformity Rule, 4-15, 4-16
Glacier, 5-23, 5-26, 5-91, 5-92
Global warming potential, 1-18, 5-20, 6-8, 6-9, 6-29
Greenhouse effect, 5-6
Greenhouse gas, 1-1, 1-2, 1-12, 2-1, 2-26, 5-1, 5-21, 5-44, 5-137, 8-1
GHG emissions standards, EPA, 1-4, 1-5, 1-6, 1-8, 1-12, 1-13, 1-23, 1-25, 2-1, 2-2, 2-12, 5-35, 5-38, 7-8, 8-3
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, 2-24, 5-33, 5-49, 6-15, 6-17
Green Book Nonattainment Areas for Criteria Pollutants, 4-20
Greenland ice sheet, 5-26, 5-150, 5-151, 5-155, 5-162, 5-197
Gross vehicle weight rating (GVWR), 1-1, 1-7, 1-8, 2-2, 2-3, 2-4, 6-4
Groundwater, 1-15, 5-89, 5-90, 5-91, 5-92, 5-93, 5-94, 5-120, 5-129, 5-170, 5-182, 5-183, 5-204, 6-14, 7-3

H

HD Engines for Vocational Vehicles and Tractors, 2-4, 2-5, 2-6, 2-7
HD Fuel Efficiency Improvement Program, 1-2, 1-3, 1-7, 1-8, 1-9, 2-1, 2-28, 4-26, 5-50
Health impacts
Monetized, 2-26, 4-27, 4-28, 4-29, 4-54, 4-55, 4-56, 4-57, 4-59, 4-60, 4-61, 4-80, 4-81, 4-82, 4-83, 4-84, 4-86, 4-87, 5-51, 5-52, 5-74
Quantified, 4-28, 4-33
Heat wave, 5-11, 5-21, 5-22, 5-58, 5-59, 5-60, 5-114, 5-133, 5-136, 5-137, 5-158, 5-159, 5-163, 5-171, 5-172, 5-173, 5-174, 5-176, 5-177, 5-180, 5-181, 5-183, 5-186, 5-187
Highway Fuel Economy Test (HFET), 2-20
Historic and cultural resources, 7-1, 7-6
Human health, 1-24, 4-2, 4-6, 4-9, 4-17, 4-27, 4-28, 4-29, 4-33, 4-56, 4-82, 5-15, 5-17, 5-28, 5-30, 5-88, 5-94, 5-128, 5-133, 5-134, 5-136, 5-137, 5-140, 5-158, 5-160, 5-163, 5-164, 5-167, 5-170, 5-171, 5-173, 5-176, 5-177, 5-178, 5-183, 5-186, 5-204, 6-14, 6-29, 7-1, 7-7, 7-8, 7-9, 7-12
Climate change, recent findings, 5-89, 5-96, 5-100, 5-133, 5-138
Human settlements, effects of climate change, 5-88, 5-127
Hurricane Katrina, 5-120, 5-124, 5-143, 5-146, 5-150
Hypoxia, 5-104

I

Ice cover, 5-5, 5-21, 5-22, 5-26, 5-144, 5-152, 5-172, 5-174
Ice sheets, melting, 5-12, 5-20, 5-21, 5-23, 5-59, 5-133
Impacts, 2-22, 2-28, 2-32, 2-33, 3-14, 3-15, 4-29, 4-33, 4-35, 4-36, 4-37, 4-39, 4-40, 4-43, 4-44, 4-45, 4-46, 4-48, 4-49, 4-52, 4-53, 4-61, 4-62, 4-63, 4-64, 4-65, 4-69, 4-70, 4-71, 4-73, 4-74, 4-75, 4-78, 4-79, 5-12, 5-17, 5-21, 5-35, 5-36, 5-37, 5-42, 5-44, 5-50, 5-52, 5-58, 5-68, 5-75, 5-83, 5-85, 5-86, 5-87, 5-90, 5-96, 5-101, 5-107, 5-117, 5-127, 5-131, 5-133, 5-136, 5-139, 5-140, 5-146, 5-150, 5-155, 5-158, 5-162, 5-204, 5-207, 5-211, 6-12, 7-1, 7-8, 7-12, 8-1
Incomplete or unavailable information, 2-27, 4-1, 4-17, 4-19, 5-2
Indian summer monsoon, 5-150, 5-155, 5-156
Intergovernmental Panel on Climate Change (IPCC), 1-15, 1-18, 2-27, 5-2, 5-3, 5-4, 5-5, 5-7, 5-8, 5-9, 5-11, 5-12, 5-13, 5-14, 5-15, 5-16, 5-17, 5-18, 5-19, 5-20, 5-21, 5-22, 5-23, 5-24, 5-25, 5-26,

5-28, 5-31, 5-33, 5-34, 5-41, 5-42, 5-52, 5-53, 5-58, 5-60, 5-61, 5-63, 5-65, 5-73, 5-75, 5-76, 5-80, 5-82, 5-89, 5-90, 5-91, 5-92, 5-93, 5-94, 5-95, 5-96, 5-97, 5-98, 5-99, 5-100, 5-101, 5-102, 5-103, 5-104, 5-105, 5-106, 5-107, 5-108, 5-110, 5-111, 5-112, 5-113, 5-114, 5-115, 5-116, 5-117, 5-118, 5-119, 5-120, 5-121, 5-122, 5-123, 5-124, 5-125, 5-126, 5-127, 5-128, 5-129, 5-130, 5-131, 5-132, 5-133, 5-134, 5-135, 5-136, 5-137, 5-138, 5-139, 5-140, 5-141, 5-142, 5-143, 5-144, 5-145, 5-146, 5-151, 5-152, 5-154, 5-156, 5-160, 5-161, 5-163, 5-168, 5-169, 5-174, 5-176, 5-179, 5-184, 5-197, 5-200, 5-201, 5-202, 5-203, 5-204, 5-205, 5-207, 5-209, 5-212, 5-213, 5-214, 5-216, 8-1
International Energy Outlook (IEO), 2-24, 3-2
Irreversible and irretrievable commitments of resources, 7-1, 7-13

J
Joint Global Change Research Institute, 2-26, 5-35, 5-36

K
Kyoto Protocol, 5-37, 5-38

M
MAGICC model, 5-30, 5-49, 5-67
Meltwater, 5-129
Methane hydrates, 5-136, 5-138
Methodologies and assumptions, 2-2, 2-24
Minority and low-income communities, 7-9
Mitigation, 5-106, 8-1, 8-2
Measures, 8-1, 8-2
Mobile source air toxics (MSATs), health effects, 4-4, 4-8, 4-9, 4-15, 4-17, 8-2
Motor Vehicle Emissions Simulator (MOVES), 2-25, 2-26, 4-14, 4-19, 5-29, 5-30, 5-33, 5-49, 6-3, 6-7
MY 2017–2025 CAFE standards, 3-8, 6-4, 6-6, 6-19, 6-20, 6-21, 6-26, 6-28

N
National Ambient Air Quality Standards (NAAQS), 4-1, 4-2, 4-3, 4-4, 4-6, 4-7, 4-11, 4-12, 4-15, 4-18, 4-29, 4-33, 4-44, 4-53, 4-70, 4-79
Maintenance areas, 4-3, 4-15, 4-18, 4-19, 4-20
Nonattainment areas, 4-1, 4-3, 4-16, 4-17, 4-18, 4-19, 4-20, 4-26, 4-27, 4-44, 4-53, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-70, 4-79, 4-82, 4-83, 4-84, 4-85, 4-86, 7-11, 7-12, 8-1, 8-2
Primary, 3-3, 4-3, 5-7, 7-7
Secondary, 4-3
National Emissions Inventory (NEI), 2-25, 2-26, 4-20, 4-27, 5-16
National Environmental Policy Act of 1969 (NEPA), 1-3, 1-14, 1-15, 1-16, 1-17, 2-1, 2-22, 2-27, 2-28, 4-16, 5-1, 5-37, 5-75, 5-158, 7-9, 8-1, 8-2
National Highway Traffic Safety Administration (NHTSA), 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 1-9, 1-12, 1-13, 1-14, 1-15, 1-16, 1-17, 1-18, 1-19, 1-20, 1-21, 1-22, 1-23, 1-24, 1-25, 2-1, 2-2, 2-3, 2-4, 2-8, 2-12, 2-14, 2-20, 2-22, 2-23, 2-24, 2-27, 3-1, 4-1, 4-16, 4-17, 4-18, 4-19, 4-20, 4-26, 4-27, 4-28, 4-29, 4-30, 4-33, 4-38, 4-62, 5-1, 5-2, 5-12, 5-27, 5-29, 5-30, 5-31, 5-32, 5-33, 5-34, 5-35, 5-36, 5-37, 5-38, 5-41, 5-42, 5-43, 5-44, 5-48, 5-51, 5-52, 5-53, 5-61, 5-65, 5-66, 5-68, 5-82, 5-86, 5-87, 5-89, 5-158, 6-1, 6-4, 6-23, 6-24, 6-25, 6-26, 6-30, 6-31, 7-1, 7-5, 7-7, 7-8, 7-9, 7-13, 8-1, 8-2, 8-3
No Action Alternative, 1-19, 2-1, 2-2, 2-4, 2-5, 2-8, 2-12, 2-14, 2-20, 2-22, 2-24, 2-25, 2-28, 2-29, 2-30, 2-31, 2-31, 2-32, 2-33, 2-34, 2-35, 3-14, 3-15, 4-1, 4-2, 4-17, 4-35, 4-38, 4-41, 4-42, 4-43, 4-47, 4-51, 4-52, 4-54, 4-55, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-62, 4-67, 4-68, 4-69, 4-70, 4-72, 4-77, 4-78, 4-80, 4-81, 4-82, 4-83, 4-84, 4-85, 4-86, 4-87, 5-1, 5-12, 5-19, 5-27, 5-29, 5-33, 5-35, 5-36, 5-41, 5-42, 5-44, 5-45, 5-46, 5-47, 5-48, 5-49, 5-51, 5-53, 5-54, 5-55, 5-56, 5-57, 5-61, 5-62, 5-65, 5-66, 5-68, 5-69, 5-70, 5-71, 5-75, 5-76, 5-78, 5-79, 5-80, 5-82, 5-83, 5-84, 5-85, 5-86, 5-87, 7-5, 7-6, 7-8, 7-9, 7-12, 7-13, 8-1, 8-2, 8-5
Noise, 7-6, 7-7
Nonattainment area, 4-1, 4-3, 4-16, 4-17, 4-18, 4-19, 4-20, 4-26, 4-27, 4-44, 4-53, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-70, 4-79, 4-82, 4-83, 4-84, 4-85, 4-86, 7-11, 7-12, 8-1, 8-2
Notice of Intent (NOI), 1-14, 1-15
Notice of Proposed Rulemaking (NPRM) , 1-2, 1-7, 1-9, 1-12, 1-13, 1-17, 1-20, 1-24, 1-25, 2-2, 2-3, 2-12, 2-20

O
Ocean acidification, 5-22, 5-26, 5-101, 5-104, 5-154, 5-169, 5-190, 5-198, 5-200, 5-203, 5-206, 5-207, 5-208, 5-209, 5-211
Ocean circulation, 5-33, 5-65, 5-101, 5-105, 5-151, 5-162, 5-182, 5-201, 5-211
Ocean productivity, 5-105

Ocean salinity, 5-19, 5-90, 5-159
Office of Management and Budget (OMB), 1-18, 5-117
Oil extraction, 4-26, 6-7, 6-12, 7-1, 7-2, 7-5, 7-11
Ozone, 1-3, 1-5, 3-1, 4-1, 4-2, 4-3, 4-6, 4-8, 4-18, 4-20, 4-21, 4-22, 4-23, 4-24, 4-25, 4-26, 4-28, 4-29, 4-32, 4-33, 4-44, 4-53, 4-70, 4-79, 5-7, 5-8, 5-34, 5-35, 5-88, 5-134, 5-136, 5-146, 5-147, 5-148, 5-149, 5-150, 5-163, 5-170, 5-176, 5-186, 5-214, 5-215, 5-216, 6-2, 6-21, 7-3

P

Permafrost, 5-19, 5-23, 5-25, 5-26, 5-91, 5-92, 5-99, 5-103, 5-122, 5-123, 5-124, 5-131, 5-140, 5-143, 5-150, 5-155, 5-157, 5-192, 5-197, 5-198, 5-199, 5-204, 5-206
Phenology, 5-83, 5-84
Polar regions, 5-104, 5-147, 5-148, 5-149, 5-150
Pollution controls, 4-2
Population growth, 5-120, 5-129, 5-184, 5-186, 5-189
Poverty, 5-115, 5-133, 5-145, 5-204, 5-207, 7-9
Precipitation patterns, changes in, 5-25, 5-99, 5-102, 5-107, 5-108, 5-109, 5-164, 5-177, 5-186, 5-187
Preferred Alternative, 1-3, 1-17, 1-19, 1-22, 2-2, 2-3, 2-6, 2-7, 2-9, 2-10, 2-12, 2-13, 2-16, 2-18, 2-20, 2-27, 3-15, 3-16, 3-17, 4-1, 4-38, 4-39, 4-41, 4-47, 4-48, 4-57, 4-58, 4-59, 4-60, 4-61, 4-64, 4-72, 4-74, 4-83, 4-84, 4-85, 4-86, 4-87, 5-35, 5-36, 5-41, 5-42, 5-48, 5-66, 5-68, 5-82, 5-83, 5-84, 5-85, 5-86
Preservation, 5-189, 7-2, 7-6, 8-1
President Obama, 1-3, 1-6, 3-1, 5-44, 8-5
Primary fuels, U.S. production and consumption, 3-3, 3-6
Proposed Action, 1-1, 1-2, 1-4, 1-5, 1-6, 1-9, 1-12, 1-13, 1-15, 1-16, 1-19, 1-24, 2-1, 2-23, 2-24, 2-27, 3-1, 3-3, 3-6, 3-7, 3-9, 3-10, 4-1, 4-14, 4-16, 4-17, 4-18, 4-19, 4-26, 4-32, 4-35, 4-45, 4-61, 4-72, 5-1, 5-12, 5-16, 5-19, 5-28, 5-44, 5-46, 5-48, 5-50, 5-51, 5-52, 5-61, 5-68, 5-69, 5-70, 5-73, 5-75, 5-76, 5-86, 5-158, 6-1, 7-1, 7-3, 7-4, 7-5, 7-6, 7-8, 7-10, 7-11, 7-12, 8-2, 8-6

R

Reasonably foreseeable future action, 2-22, 2-28, 2-32, 3-14, 4-35, 5-1, 5-27, 5-44, 5-68, 5-69, 5-70, 5-75
Rebound effect, 2-25, 4-16, 4-17, 4-18, 4-57, 4-58, 4-59, 4-60, 4-83, 4-84, 4-85, 4-86, 7-11
Regional Greenhouse Gas Initiative (RGGI), 5-37, 5-50, 5-51
Renewable Fuel Standard (RFS2), 2-24, 5-39, 8-3
Runoff, 5-90, 5-91, 5-94, 5-98, 5-102, 5-106, 5-119, 5-120, 5-124, 5-162, 5-169, 5-176, 5-177, 5-179, 5-181, 5-182, 5-184, 5-187, 5-215, 6-13, 7-2

S

Safety impacts, 1-21, 1-23, 7-1
Salinity, 5-26, 5-102, 5-104, 5-105, 5-120, 5-168, 5-204
Saltwater intrusion, 5-103, 5-120, 5-164, 5-168, 5-169, 5-170, 5-202, 5-203, 5-206
SCC Technical Support Document (SCC TSD), 5-30, 5-32
Sea-level rise, 2-30, 2-35, 5-7, 5-14, 5-22, 5-23, 5-24, 5-34, 5-41, 5-44, 5-52, 5-54, 5-65, 5-66, 5-67, 5-68, 5-75, 5-76, 5-82, 5-83, 5-84, 5-85, 5-86, 5-87, 5-91, 5-93, 5-97, 5-101, 5-102, 5-103, 5-104, 5-106, 5-119, 5-120, 5-121, 5-123, 5-124, 5-125, 5-127, 5-131, 5-132, 5-143, 5-151, 5-154, 5-159, 5-160, 5-161, 5-162, 5-163, 5-164, 5-165, 5-166, 5-168, 5-169, 5-182, 5-187, 5-188, 5-192, 5-197, 5-200, 5-201, 5-202, 5-203, 5-204, 5-207, 7-11, 7-12
Sea-surface temperature, 5-156
Secretary of Transportation, 1-1, 7-9
Section 1605b Voluntary Reporting of Greenhouse Gases, 8-5
Sensitivity analyses, 4-29, 5-29, 5-30, 5-31, 5-38, 5-39
Short-term uses and long-term productivity, 7-1, 7-13
Sleeper cab, 1-8, 2-3, 2-8
Social Cost of Carbon (SCC), 1-18, 5-27, 5-30, 5-31, 5-32, 5-51, 5-73, 5-87
Soil, 1-15, 4-8, 5-92, 5-93, 5-107, 5-109, 5-110, 5-113, 5-116, 5-124, 5-125, 5-129, 5-157, 5-170, 5-182, 5-189, 5-198, 5-206, 5-207, 5-208, 5-211, 5-212, 5-214, 5-215, 5-216, 6-7, 6-16, 7-4
Solar energy, 5-7
Solar radiation, 4-7, 5-7, 5-136
Southern Oscillation, 5-93, 5-150, 5-155, 5-156, 5-200
Special Report on Emission Scenarios (SRES), 5-34, 5-60, 5-65, 5-211
Species genetics
Species morphology
Species reproduction
Speed limits

Standards, 1-2, 1-5, 1-6, 1-7, 1-14, 2-2, 2-5, 2-6, 2-8, 2-9, 2-10, 2-11, 2-13, 2-14, 2-15, 2-16, 2-17, 2-18, 2-19, 2-20, 2-21, 4-1, 4-3, 4-4, 4-8, 4-13, 4-29, 5-37, 5-38, 5-39, 5-40, 5-51, 5-52, 5-74, 6-4, 8-3, 8-4
Compliance, 2-8, 2-14, 2-20, 2-23, 4-18
Statutory authorities
Stratospheric ozone, 5-88
State Implementation Plan (SIP), 4-3, 4-15, 5-38
Statutory authority, 1-7, 4-16
Stringency, 1-2, 1-12, 1-22, 2-2, 2-3, 2-12, 2-20, 4-47, 4-54, 4-72, 4-80, 5-44, 5-69
Supplemental Engine Test (SET), 2-4, 2-5, 2-6, 2-7
Surface warming, 5-41, 5-58, 5-61, 5-80
Survival rate, 5-109, 5-206
Synthesis and Assessment Product (SAP), 5-28, 5-34, 5-35, 5-36

T

Temperature, change in, , 1-20, 2-26, 2-27, 2-30, 4-8, 4-15, 5-1, 5-5, 5-6, 5-11, 5-12, 5-14, 5-15, 5-22, 5-23, 5-24, 5-25, 5-27, 5-31, 5-33, 5-34, 5-40, 5-41, 5-42, 5-44, 5-52, 5-53, 5-54, 5-56, 5-58, 5-59, 5-60, 5-61, 5-62, 5-63, 5-65, 5-66, 5-67, 5-68, 5-73, 5-75, 5-76, 5-80, 5-82, 5-83, 5-84, 5-85, 5-86, 5-87, 5-90, 5-92, 5-97, 5-98, 5-99, 5-103, 5-104, 5-105, 5-108, 5-109, 5-110, 5-111, 5-112, 5-113, 5-114, 5-119, 5-121, 5-123, 5-125, 5-126, 5-128, 5-129, 5-130, 5-131, 5-132, 5-133, 5-135, 5-136, 5-137, 5-140, 5-147, 5-148, 5-150, 5-154, 5-156, 5-157, 5-158, 5-159, 5-160, 5-163, 5-164, 5-165, 5-166, 5-167, 5-170, 5-174, 5-176, 5-177, 5-180, 5-181, 5-183, 5-185, 5-187, 5-188, 5-190, 5-192, 5-194, 5-195, 5-201, 5-202, 5-205, 5-211, 5-212, 5-215, 5-216, 6-3, 6-11, 6-29, 7-6, 7-11, 7-12
Terrestrial and freshwater ecosystems, 5-87, 5-96, 5-158, 5-164, 5-167, 5-173, 5-178, 5-183, 5-188, 5-192, 5-196, 5-201, 5-202
Test methods, 1-1, 1-3, 1-23
Tipping point, 1-18, 5-42, 5-86, 5-89, 5-99, 5-103, 5-150, 5-151, 5-155, 5-158
Tipping points and abrupt climate change, 5-42, 5-43, 5-151
Topography, 5-14, 5-186
Tractors, 1-1, 1-5, 1-8, 1-9, 1-10, 1-11, 1-12, 1-22, 2-2, 2-3, 2-4, 2-5, 2-6, 2-7, 2-8, 2-9, 2-10, 2-11, 2-12, 2-22, 6-23, 6-25, 6-28, 7-7
Tractor Diesel Engine Standards, 2-5, 2-6, 2-7
Traffic, 4-4, 4-5, 4-18, 4-20, 5-122, 5-199, 6-13, 6-27, 7-6, 7-7, 7-8, 7-9, 7-10
Transient (urban) driving, 6-27
Transit system, 5-123, 5-161
Transportation, 1-1, 1-7, 1-8, 1-15, 1-18, 1-20, 1-22, 1-24, 2-3, 2-23, 2-24, 2-25, 3-1, 3-3, 3-6, 3-7, 3-8, 3-10, 3-16, 4-2, 4-15, 4-26, 4-27, 5-8, 5-9, 5-16, 5-20, 5-21, 5-27, 5-29, 5-37, 5-38, 5-46, 5-48, 5-50, 5-68, 5-73, 5-86, 5-88, 5-102, 5-107, 5-115, 5-117, 5-120, 5-123, 5-124, 5-125, 5-127, 5-131, 5-137, 5-145, 5-162, 5-176, 5-190, 5-192, 5-204, 6-1, 6-2, 6-3, 6-4, 6-10, 6-11, 6-18, 6-29, 7-3, 7-7, 7-9, 8-1, 8-2, 8-4, 8-5
Transportation systems, effects of climate change, 5-124
Tundra loss, 5-136, 5-138

U

Uncertainty, 1-20, 2-27, 4-11, 4-20, 4-26, 4-31, 4-33, 5-2, 5-3, 5-5, 5-16, 5-18, 5-27, 5-28, 5-32, 5-89, 5-91, 5-94, 5-120, 5-146, 5-147, 5-149, 5-157, 5-159, 5-161, 6-6, 6-8, 6-30, 7-5, 7-8
Uncertainty guidelines, 5-77
United Nations Framework Convention on Climate Change (UNFCCC), 5-31, 5-39, 5-48
Upstream emissions, 1-23, 2-23, 2-24, 2-25, 4-17, 4-26, 4-27, 4-29, 4-41, 4-47, 4-57, 4-58, 4-59, 4-60, 4-67, 4-72, 4-83, 4-84, 4-85, 4-86, 5-29, 5-30, 5-33, 5-35, 5-49, 6-1, 6-2, 6-3, 6-5, 6-6, 6-7, 6-29, 6-30, 7-11
U.S. Census Bureau, 5-127, 5-186
U.S. Climate Change Technology Program, 8-5
U.S. Department of Energy (DOE), 1-2, 1-13, 1-14, 1-19, 2-1, 2-23, 2-24, 2-25, 2-26, 3-2, 4-17, 5-29, 5-39, 5-122, 6-16, 6-24, 6-26, 6-30, 8-4, 8-5
U.S. Department of Health and Human Services (DHHS), 4-9, 4-11
U.S. Department of Transportation (DOT), 1-1, 1-3, 1-5, 1-13, 1-14, 1-15, 1-16, 1-17, 1-21, 1-25, 4-29, 4-30, 4-31, 4-32, 5-1, 5-30, 5-123, 5-124, 5-128, 5-162, 7-9, 7-10, 8-5
U.S. Environmental Protection Agency. See EPA
U.S. Geological Survey (USGS), 5-25
U.S. Global Change Research Program (GCRP), 5-2, 5-3, 5-5, 5-6, 5-11, 5-12, 5-14, 5-21, 5-22, 5-23, 5-24, 5-25, 5-26, 5-28, 5-42, 5-89, 5-90, 5-91, 5-92, 5-93, 5-94, 5-96, 5-97, 5-98, 5-100, 5-101, 5-102, 5-103, 5-104, 5-106, 5-107, 5-108, 5-109, 5-110, 5-111, 5-114, 5-115, 5-116, 5-117, 5-118, 5-

119, 5-120, 5-121, 5-122, 5-123, 5-124, 5-125, 5-127, 5-128, 5-129, 5-131, 5-132, 5-134, 5-135, 5-136, 5-137, 5-138, 5-140, 5-141, 5-143, 5-145, 5-146, 5-152, 5-153, 5-154, 5-155, 5-156, 5-158, 5-159, 5-160, 5-161, 5-162, 5-163, 5-164, 5-165, 5-166, 5-167, 5-168, 5-169, 5-170, 5-171, 5-172, 5-173, 5-174, 5-176, 5-177, 5-179, 5-180, 5-181, 5-182, 5-183, 5-184, 5-185, 5-186, 5-187, 5-188, 5-189, 5-190, 5-192, 5-194, 5-195, 5-196, 5-197, 5-198, 5-199, 5-200, 5-201, 5-202, 5-203, 5-204, 5-205, 5-206, 5-207, 5-209, 5-211, 5-212, 5-215, 5-216
U.S. population, 4-4

V
Vegetation, 4-1, 4-2, 4-6, 5-7, 5-98, 5-99, 5-110, 5-113, 5-119, 5-125, 5-161, 5-168, 5-185, 5-186, 5-189, 5-208, 5-214
Vehicle manufacturers, 1-20, 2-8, 2-14, 4-16, 4-19, 6-1, 7-8, 7-9, 7-13
Vehicle-miles travelled (VMT), 1-16, 1-20, 2-23, 2-24, 2-27, 4-14, 4-15, 4-16, 4-18, 4-19, 4-20, 4-35, 4-38, 4-41, 4-45, 4-47, 4-56, 4-61, 4-62, 4-67, 4-72, 4-82, 5-47, 5-48, 5-51, 5-71, 5-73, 7-2, 7-7, 7-8, 7-11, 7-12
Vocational vehicles, 1-5, 1-8, 1-10, 1-11, 1-13, 1-19, 1-22, 2-2, 2-3, 2-4, 2-5, 2-6, 2-7, 2-14, 2-15, 2-16, 2-18, 2-19, 2-22, 2-23, 2-25, 3-14, 4-38, 4-65, 5-30, 6-25, 6-26
Vocational Vehicle Diesel Engine Standards, 2-6, 2-7, 2-8
Volpe model, 5-26, 5-27

W
Waste, 1-10, 1-21, 5-9, 5-15, 5-20, 5-116, 5-120, 5-162, 5-163, 6-2, 6-3, 6-12, 6-14, 6-17, 6-20, 6-23, 6-29, 7-1, 7-2, 7-3, 7-4, 7-5, 8-4
Water quality, 5-90, 5-93, 5-94, 5-107, 5-120, 5-129, 5-132, 5-177, 5-179, 5-204, 6-2, 6-20, 7-1, 7-2
Water resources, 5-94, 5-129, 5-135, 5-138, 5-145, 5-179, 5-180, 5-189, 5-205, 5-206, 7-2
Water supply, 5-94, 5-95, 5-120, 5-122, 5-126, 5-160, 5-184
Water utilities, effects of climate change, 5-94
Weather, severe, increased incidence, 5-22, 5-123, 5-125, 5-132
West African monsoon, 5-131, 5-136, 5-137
West Antarctic ice sheet, 5-26, 5-150, 5-152, 5-155
World Meteorological Organization (WMO), 5-15, 5-146, 5-147, 5-149, 5-150