**TASK ORDER 0003 UNDER**
**CONTRACT DTNH22-13-D-00298**

# PEER REVIEW OF "COMMERCIAL MEDIUM- AND HEAVY-DUTY (MD/HD) TRUCK FUEL EFFICIENCY TECHNOLOGY STUDY – REPORT #1"

## PEER REVIEW REPORT
## February 20, 2015

*Submitted to:*
**U.S. Department of Transportation**
**National Highway Traffic Safety Administration**
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# 1.0 INTRODUCTION

This report documents the results of an independent external peer review of the draft publication *Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #1,* developed by Southwest Research Institute (SwRI) for the National Highway Traffic Safety Administration (NHTSA). Eastern Research Group, Inc. (ERG, a contractor to NHTSA) organized this review and developed this report. The report provides background about the review (Section 2), describes the review process (Section 3), and presents reviewer comments organized by charge question (Section 4). Appendices A, B, and C, respectively, provide reviewer curriculum vitae, the charge to reviewers, and the individual comments submitted by each of the six reviewers.

# 2.0 BACKGROUND

In September 2012, NHTSA competitively awarded a contract to SwRI to conduct research in support of the next phase of Federal fuel efficiency (FE) and greenhouse gas (GHG) standards. Tasks included determining the baseline fuel efficiency and emissions levels and technologies of current model year commercial medium- and heavy-duty on-highway vehicles and work trucks, as well as projections of Phase 2 (post-2018 model year) fuel efficiency and emission reduction technologies. The scope encompassed technologies for chassis and final-stage manufacturer vehicles and trailers, maintenance cost, material application, future design, electric and hybrid propulsion systems, capital investment, retail cost/payback, and any other applicable advanced technologies. Estimates of the costs, fuel savings effectiveness, availability, and applicability of technologies were done for each individual vehicle class category (e.g., segment).

The resulting report series consists of three sequential reports. All three reports are from the same project, and involve the same technologies, engines, and vehicles; however, due to their large size, they have been separated into three documents to facilitate review and publication. This review covers the first of these reports. The first report contains an assessment of the current commercial fleet technology baseline at the time of contract award (MY 2011/2012) and an assessment of the effectiveness and cost of potential fuel efficiency/GHG-improving technologies.

# 3.0 PEER REVIEW PROCESS

## 3.1 Reviewer Search and Selection

For this review, ERG identified, screened, and selected six reviewers who had no conflict of interest (COI) in performing the review and who collectively met the following technical selection criteria provided by NHTSA:

**Expertise with MD/HD Vehicles**

- Expertise in fuel consumption/GHG reduction technologies for MD/HD on-highway vehicles and work trucks, including their engines and trailers.
- Expertise in MD and/or HD truck vocation and duty cycles.
- Expertise in global fuel economy/GHG regulations.
- Expertise in engine fuel consumption map simulations (gasoline and diesel).
- Expertise in whole vehicle fuel consumption simulations (Greenhouse Gas Emissions Model [GEM] or comparable software) over vehicle drive-cycles (Class 2b-8 trucks, including combination tractors, heavy-duty pickup trucks and vans, and vocational vehicles).
- Expertise in fuel economy/emissions regulatory test procedures and drive cycles.

**Expertise with LD Vehicles**

- Expertise in fuel consumption/GHG reduction technologies.
- Expertise in global fuel economy/GHG regulations.
- Expertise in engine fuel consumption map simulations (gasoline and diesel).
- Expertise in whole vehicle fuel consumption simulations over vehicle drive-cycles.
- Expertise in fuel economy/emissions regulatory test procedures and drive cycles.

ERG developed an initial list of potential candidates who appeared, based on publicly available information, to meet the above criteria. After receiving NHTSA confirmation that the candidates were suitably qualified and had no obvious COI, ERG contacted these candidates to ascertain their interest and availability to perform the review. Interested candidates provided their curriculum vitae (CV), completed and signed a detailed COI form, and signed a non-disclosure agreement (NDA). After carefully reviewing this additional information, ERG selected six candidates who collectively best met the selection criteria and had no conflict in performing the review. ERG provided their CVs, signed NDAs, and certification of lack of COI to NHTSA. After receiving NHTSA verification that the proposed reviewers were appropriately qualified, ERG contracted with them to conduct the review. The reviewer team, in alphabetical order by last name, comprised:

**Dr. Matthew J. Barth,** Yeager Families Professor at the College of Engineering, University of California-Riverside (UCR). Dr. Barth is part of the intelligent systems faculty in Electrical Engineering and is also serving as the Director for the Center for Environmental Research and Technology (CE-CERT), UCR's largest multi-disciplinary research center. His research focuses on applying engineering system concepts and automation technology to transportation systems, and in particular how it relates to energy and air quality issues. His current research interests include intelligent transportation systems (ITS) and the environment; transportation/emissions modeling; vehicle activity analysis; advanced navigation techniques; electric vehicle technology; and advanced sensing and control. Dr. Barth is active with the U.S. Transportation Research Board serving in a variety of roles in several committees, including the Committee on ITS and the Committee on Transportation Air Quality. He was awarded the TRB Pyke Johnson Award for TRB outstanding paper in 2007. In 2011, he was one of the winners of the Connected Vehicle Technology Challenge sponsored by U.S. Department of Transportation's Research and Innovative Technology Administration (RITA). He has also served on a number of National Research Council (NRC) Committees.

Ph.D., Electrical and Computer Engineering, University of California-Santa Barbara, 1990
M.S., Electrical and Computer Engineering, University of California-Santa Barbara, 1986

**Dr. William de Ojeda,** Director of Engineering, WM International Engineering, LLC. Dr. de Ojeda joined WM International Engineering in 2014 and is currently responsible for development of fuel injection and charge air systems for advanced diesel, gasoline, natural gas, dual fuel, and alternative fuel powertrains. His work includes design, prototyping, controls, and benchmarking. He was previously with Navistar, Inc. for 17 years where he was a Senior Product Engineer of advanced technologies and Manager of advanced combustion and controls. In 1990, Dr. de Ojeda received the Stefano Excellence Capstone Design Award for "A Microcomputer-Interfaced Steam Turbine Test Stand."

Ph.D., Mechanical and Aerospace Engineering, Illinois Institute of Technology, 1996
M.Sc., Mechanical and Aerospace Engineering, University of Virginia, 1992

**Mr. Dana M. Lowell**, Senior Vice President & Technical Director, M.J. Bradley & Associates LLC (MJB&A). Mr. Lowell has 25 years professional experience in the transportation and government sectors. He has worked in MJB&A's advanced vehicle technology group since 2004, providing strategic analysis, project management,

and technical support to mobile source emissions reduction programs. His mobile source project work includes evaluation and implementation of advanced diesel emissions controls, alternative fuels, and advanced hybrid and fuel cell electric drives, as well as development and implementation of diesel emissions testing programs for a range of on-road and non-road heavy-duty vehicle types.

M.B.A., co-major in Management and Operations Management, New York University, 1995
B.S., Mechanical Engineering, Princeton University, 1985

**Dr. Shawn Midlam-Mohler,** Assistant Professor, Department of Mechanical and Aerospace Engineering, Ohio State University (OSU); Associate Director, OSU's Simulation Innovation and Modeling Center; OSU-CAR Associate Fellow, Center for Automotive Research; and Director of OSU Motorsports in the College of Engineering. Dr. Midlam-Mohler maintains an active research program focused in the area of model-based design of complex systems. His teaching focuses on automotive technical electives, capstone senior design, and most recently a course on project management and systems engineering. He has also developed a number of courses in his area of expertise for the Department of Energy (DOE) sponsored advanced technology vehicle competition program.

Ph.D., Mechanical Engineering, Ohio State University, 2005
M.S., Mechanical Engineering, Ohio State University, 2001

**Ms. Susan M. Nelson,** Owner and Managing Member, Blue Stripe Scientific, LLC. Ms. Nelson is a project manager with over 12 years of experience piloting teams in new product research and development (R&D), test development and validation, manufacturing, quality assurance, and public-private research partnerships. Currently as a Project Manager and technical service provider, she assesses approaches to monitor and maintain inflation pressure in heavy-duty vehicle tires, under contract to the North American Council for Freight Efficiency (NACFE). She has defined categories of technologies to permit characterization of diverse product offerings according to common features and functionalities. She is highly familiar with various tire pressure technologies.

M.S., Civil Engineering, Massachusetts Institute of Technology, 1979
B.S., Civil Engineering, Massachusetts Institute of Technology, 1977

**Dr. John P. Nuszkowski**, Assistant Professor, Mechanical Engineering Program, University of North Florida. Dr. Nuszkowski's research includes vehicle powertrain optimization, in-use vehicle emissions, advanced combustion, alternative fuels, and large-bore diesel emissions reduction. His research goals are to improve vehicle fuel economy by operating vehicles more efficiently and improve air quality by reducing the exhaust emissions from engines and vehicles through improved combustion of petroleum-based fuels and use of alternative fuels. Since 2008, he has conducted research for heavy-duty vehicle and engine performance and emissions.

Ph.D., Mechanical Engineering, West Virginia University, 2008
M.S., Mechanical Engineering, West Virginia University, 2005

Reviewer curriculum vitae/resumes are provided in Appendix A.

## 3.2 Conducting the Review

ERG provided reviewers with the review document and the charge to reviewers (Appendix B). To kick off the review, ERG organized a 1-hour briefing call. During this call, which was facilitated by ERG, NHTSA provided background about the purpose and development of the review document, and reviewers had the opportunity to ask questions of clarification regarding the charge and review process.

After this call, reviewers worked individually (i.e., without further contact with other reviewers or NHTSA) to prepare written comments in response to the charge questions. During this time, two reviewers sent additional questions of clarification to ERG. ERG forwarded these questions to NHTSA and provided NHTSA's responses to all six reviewers.

Reviewers completed their reviews and submitted their written comments to ERG, and ERG provided them to NHTSA. Both ERG and NHTSA checked the comments to ensure that reviewers had responded clearly to all charge questions. NHTSA requested one clarification, and ERG forwarded this request to the relevant reviewer. ERG added the clarification to the reviewer's comments and then prepared this peer review report. Section 4 of this report presents reviewer comments organized by charge question, and Appendix C provides the comments by reviewer. In both cases, comments are presented exactly as submitted, without editing, summarizing, or correction of typographical errors (if any).

# 4.0 REVIEWER COMMENTS ORGANIZED BY CHARGE QUESTION

This section presents reviewer comments organized by charge question. Comments are copied directly from written comments as submitted by each reviewer and presented in Appendix C.

## 4.1 Literature Review

### 4.1-1 Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel-saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included this section and explain why they would be helpful.

**Barth**

- Overall, the literature review provided in the report seems fairly complete. A few comments are provided below.
- The engine and vehicle fuel savings technology ((1) listed above) seems fairly complete, with some commentary below:
    - Section 2.3.1.4: nicely written, I wonder if there are some references that show how downsizing and turbocharging benefits vary across different driving cycles.
    - Section 2.3.1.5: misspelling of 2025 (20205).
    - Section 2.3.1.6: idle reduction is now a hot topic, particularly in the light duty "start-stop technology" arena. I wonder if additional references beyond the single truck reference can be provided.
    - Section 2.3.3: shouldn't there be a section on lean-burn control technology, and the trade off with NOx emissions? Maybe this is in a different section. This could also be highlighted in Section 2.3.4.

- Is the paragraph in section 2.3.5 on engine downspeeding in the right place?
- In section 2.3.5.2: any mention of potential fuel economy improvements?
- In section 2.4.2.2, there are now some more recent truck aerodynamic studies, sponsored by CARB, being conducted by NREL and UCR CE-CERT. It would be good to reference these.
- Section 2.4.2.3: similarly, there has been a significant amount of new research results on hybrid drivetrains since 2012; visiting the DOE Vehicle Technology Research website cites many of these new studies.

- The approach and references for market segmentation ((2) listed above) seem appropriate, using the most up-to-date sources. This reviewer does not know of any other sources that may be better.
- For the worldwide fuel efficiency regulations ((3) listed above), I wonder if the report can comment more on the potential "good practices" and "bad practices" of the other methods used in different parts of the world. For example, the approach used by China using a single driving cycle seems somewhat limited in the results they can produce. Also, the Japanese top runner program focuses on engine efficiency, not vehicle efficiency (as the report states); however, I believe Japan's JCAP and related programs (see, e.g., http://www.pecj.or.jp/english/jcap/jcap1/index_jcap1.html) have done more extensive vehicle fuel economy testing.
- Strangely missing from the worldwide fuel regulation literature is what the European Commission is doing… This should be included in the report.
- Section 2.2.3 primarily only discusses the fuel efficiency test and analysis methodology used in this report; some additional language should be provided on other methods, including a big emphasis on using vehicle activity data sets rather than just using "representative" driving cycles.

**de Ojeda**

***1. Addressing key data sources of fuel saving technologies for MD/HD engines and vehicles.***

The **Engine Technologies** section (2.3) provides a brief overview of major technologies that have risen in the last years and have made their way into the LD and HD markets. The treatment is consistent: the report is brief, highlights one or two significant points, and makes one to three references for each category.

The approach is adequate given the very extensive literature available. This section may be improved by indicating the relative success or the acceptance of these technologies onto OEM products.

This first part of this section focuses on spark ignition engines before transitioning to Diesel. Under the gasoline category, other systems could be included. A few suggestions are given here for more completeness: VVA, Atkinson cycle, Miller cycle (addressed in part on *2.3.1.4*).

The **Vehicle Technologies** section (2.4) is also very concise across the technologies reviewed, with few representative references quoted. Review of these references fail to give any useful information to the reader. Some examples are given below.

- On page 15. The authors can give more detail as to what technologies are considered. "*In a study by Saricks… various technologies is considered [VT-10]. A base case, in which innovation proceeds at its current pace, and an accelerated implementation pace, are considered… Both engine and vehicle technologies are considered*."

- On page 15. The authors discuss the type of study rather than provide a useful summary to the reader. "*A particular medium duty vehicle was evaluated in an Argonne study [VT-13]. Technologies including aerodynamic drag reduction, rolling resistance reduction, transmission improvements, and vehicle weight reduction were applied to a baseline vehicle. Each technology was considered individually, and then various technology groupings were studied*."

***2. Addressing key data sources of market segmentation of fleets.***

This appears to be the area addressed in Specific Requirement (SR 3), which according to the stamen on top of page 3, was not completed. Only brief references to market segmentations are given in the text.

The report would have gained a lot from the documented performance and fuel consumption on a wider range of products. As this effort continues, this may be manageable by contacting a number of well known fleets that track very carefully these benchmarks. The information would complement the more detail data made available from the chosen platforms.

***3. Addressing current and planned MD/HD fuel economy regs in markets around the world.***

This reviewer finds the review of fuel economy regulations very weak.

In section 2.2.1, pertaining North American Fuel Economy regulations, further discussion is needed on EPA/NHTSA Phase 1 regulations (page iii, 1, 5). This being such a significant grounding point for the work undertaken, rather than limiting to a reference to the EPA website, the present report should describe and outline here the 1st and second stages. Specifically:

a. Insert a tabular representation the GHG targets.

b. Indicate how did OEM companies comply with GHG targets.

c. Show GHG standards with industry average, high and low market entries.

d. Tabulate GHG emissions for these engines vs. technologies that are being carried.

In Section 2.2.2 Worldwide FE regulations, Chinese and Japanese regulations are discussed. A summary with CO2 g/bhp-hr benchmarks should be included as noted in the earlier North American section and inserted in tabular form. Insert references.

Euro regulations are not covered here and should be included as well. Insert reference.

***Other Observations:***

The report could be enhanced (specially the review section) by highlighting what technologies have the major OEMs adopted and their relative fuel improvements towards the 2014 and 2017 GHG targets.

***Corrections and Typos:***

- Page 7 insert "of refeference [R-7]" in sentence *Pages 23 through 28 "of reference [R-7]" discuss* …
- Page 9: "viable in the 201~~0~~5 time frame"
- Page 9: "de ~~Ojeta~~ [Ojeda] reports"
- Finish sentence on page 9: "eclectic power, ~~then~~ [whereupon it is] re-condensed [prior to pumping it again into the boiler unit]."

- Sentence on page 12 mixes EGR /air handling aspects with aftertreatment. Should be deleted or corrected. "*Sisken projects a two percent fuel efficiency improvement through reduced EGR ~~(thinner wall DPF, improved SCR cell density, and catalyst material optimization)~~ [ET-18]*".

- There is considerable overlap in section 2.3.5.1 Variable Displacement Lube Pump with the previous section. Earlier section addresses several references that benchmarked variable oil pumps. Similarly, the section closes with one statement on variable speed water pumps, also covered in earlier section. Authors may want to revisit these sections.

**Lowell**

(1) Fuel saving Technologies

- The literature review appears to be comprehensive and to include key data sources for most available fuel savings technologies for MD/HD vehicles and engines.

- Specifically for electric accessories (Section 2.4.2.7) there may be other data sources available detailing in-use experience with electric cooling fans on transit and coach buses, as this approach has become more common in the past five years.

(2) Market Segmentation of Fleets

- Other data sources on market segmentation may be available. For example, in 2009 the International Council on Clean Transportation produced information on market segmentation by vehicle type, based on vehicle registration data collected by R.L. Polk & Company (attached).

- It is difficult for the reader to assess the validity of the chosen CalHEAT market segmentation approach because the report does not contain sufficient information describing it. There should be examples of the types of vehicles that would be included in each of the six segments, especially the differences between segments 2, 3, and 4; i.e., what is the difference between a Vocational Work Truck and a Work Site Support Truck? Which of these segments would the following vehicle types fall into: transit bus, coach bus, school bus, refuse truck, dump truck, utility truck, concrete truck?

- Also, there should be some discussion of the percentage of in-use vehicles, annual miles, and annual fuel use accounted for by each of the six segments.

(3) Current and Planned MD/HD Fuel Economy regulations in Markets around the World

- This section appears comprehensive with respect to the U.S., China and Japan, and mentions Canada, but does not include any discussion of other major vehicle markets including Mexico, Brazil, and especially the European Union.

- It would be helpful to the reader to include a table that briefly summarizes current and future regulatory approaches in each country/region.

**Midlam-Moher**

The document does not contain an extensive literature review on market segmentation – there are only two non-CalHEAT references. It describes that the CalHEAT approach was adopted with input from NHTSA. Some additional info should be included justifying the reasons for adopting the CalHEAT segments (of which I am sure there are good ones.) Basically, explain in a little more detail why adopting CalHEAT segments was the right decision for the work reported on in this document.

The discussion of the fuel economy regulations has numerous references but does not aggregate/summarize them into any useful form to allowing the reader to gain knowledge. It basically states that the references exist with little information being given to the reader. This is in contrast to the technology section which provides a snapshot summary of the cited reference.

There is no specific discussion of the European Union in this section of the document in regards to fuel economy regulations.

The fuel saving technologies section appears to have sufficient selection references. There are almost always more references out there – this appears to cover the topics with an appropriate amount.

**Nelson**

**Tire rolling resistance.** Several key references discussing the influence of tire rolling resistance on vehicle fuel consumption, but which are not included in the report, are listed below. In general, they constitute a chronological progression in the approach to quantifying and simulating the effects of improvements (reductions) in tire rolling resistance, as characterized by the tire coefficient of rolling resistance, Crr, to lower fuel consumption. The various analyses include lab measurements of Crr, descriptions of full-vehicle track testing, model validation for predictions of fuel consumption, and comparisons of measured and simulated changes in fuel use as a function of rolling resistance. LaClair and Truemner (2005), particularly, demonstrated the linear relationship between rolling resistance changes and fuel savings, and that the slope of these relationships depends on drive cycle. The two subsequent papers build on this analysis to develop methodologies which permit predictions of fuel savings based only on the fuel type, weight of the vehicle, and change in Crr, relatively independently of drive cycle.

- LaClair, T.J. and Truemner, R., "Modeling of Fuel Consumption for Heavy-Duty Trucks and the Impact of Tire Rolling Resistance", SAE Paper no. 2005-01-3550, 2005.
- Barrand, J. and Bokar, J., "Reducing Tire Rolling Resistance to Save Fuel and Lower Emissions", SAE Paper no. 2008-01-0154, 2007.
- Guillou, M. and Bradley, C. "Fuel Consumption Testing to Verify the Effect of Tire Rolling Resistance on Fuel Economy", SAE Paper no. 2010-01-0763, published 04/12/2010.

**Other key sources for vehicle technologies.** The latest update of the continuing studies by the National Research Council (NRC, 2014) concerning technologies for reducing fuel consumption of commercial vehicles was published in 2014. The NRC forecasts the release of a final report on technologies in 2016.

An annual summary of adoption rates of fuel-savings engine technologies, vehicle technologies, and fleet operational practices in 10 major North American fleets has been published by the North American Council for Freight Efficiency (NACFE, 2014), beginning in 2011 and most recently updated in August 2014. The study covers the period from 2003 through 2013. This reference can provide insights on technology penetration rates, particularly from an end-user perspective. While many of the technologies tracked in the NACFE study have been considered and/or incorporated into the SwRI report, the NACFE report also reflects user-driven demand, that is, deployment of new equipment or methodologies which have been seen to be valuable from a fleet viewpoint including not only fuel savings, but also life-cycle costs and maintainability.

NACFE has also produced reports on specific heavy truck technologies, including tire pressure monitoring and maintenance systems (NACFE, 2013), 6x2 axles (NACFE, Jan 2014), options for idle reduction (NACFE, June 2014), and automated transmissions (NACFE, Dec 2014).

Automatic tire inflation systems (ATIS) were mentioned by SuperTruck participants (Delgado and Lutsey, 2014) as an off-the-shelf technology that could provide additional fuel savings via more precise control of tire pressure. For several reasons, ATIS was not included as an element of the technology package considered for Phase 1 rulemaking. If a vehicle market survey can be pursued as part of Phase 2 standards development, it may be possible to concurrently obtain an updated baseline of the extent of tire underinflation in truck fleets, and to reconsider the practicality of including ATIS in future technology packages. A new tire inflation technology under development (but which is unlikely to be of sufficient maturity for several years) is an automatic inflation system that is completely contained within the lower sidewall of commercial tires. This product is described at the following site: http://www.goodyear.com/cfmx/web/corporate/media/news/story.cfm?a_id=1040. The inflation system is an integral part of the tire in this technology, in contrast to tire pressure monitoring systems (TPMS) or ATIS solutions, which can be disabled.

Another approach under study uses lift-axle capability to transfer load across axles in a tandem configuration in order to optimize the effective rolling resistance contribution of the tandem to the overall vehicle. Algorithms were developed based on knowledge of tire load-carrying and traction properties to improve fuel-savings while properly maintaining other functionalities. The improvement comes from exploitation of the small non-linearity of tire Crr as a function of load. Effectively, the tire is more efficient at high loads. (For working purposes, though, this should not perturb other analyses which set Crr as a constant with respect to load.) The patented methodology is described in Clayton and Bradley (2013).

**Market segmentation.** Several industry organizations conduct annual market surveys of fleets in an effort to assess the numbers and types of commercial vehicles in service, fleet operational costs, and trends in miles traveled and vehicle trade cycles. The American Transportation Research Institute (ATRI) has published its most recent analysis in 2014. A copy of the survey questions used is included in Appendix A of the ATRI report.

**Global fuel economy regulations.** An up-to date-summary of worldwide fuel consumption and emissions regulations, both current and planned, is contained in the 2014 State of Clean Transport Policy report by the International Council on Clean Transportation (Miller and Facanha, 2014). In addition to the US, China, and Japan, Canada is the 4$^{th}$ nation to adopt fuel consumption standards for heavy-duty vehicles. At this time, Canada is expected to align with US standards for the period covered in Phase 2 rulemaking. The ICCT report covers both light- and heavy-duty regulatory trends.

The European approach for tire labeling for fuel economy is described briefly by the European Tyre and Rubber Manufacturers' Association. It is an alternative approach for grading tires for fuel consumption, and informing consumers of the fuel efficiency of their tires. The use of up to 7 grade levels for tire Crr is presented, according to measurements using the ISO 28580 tire rolling resistance laboratory method.

**Nuszkowski**

**(1) fuel saving technologies for MD/HD engines and vehicles**

The literature review was adequate for this study. Most publications only test a single (or few) operating condition(s). It would be nice to have at least one reference (and a paragraph) on each of the engine technologies and vehicle technologies investigated. Some areas that were lacking references were asymmetric turbochargers and Stoich EGR.

In your literature review on single wide tires, you mention that single wide tires save weight. Is this including the weight of a carrying spare that many trucking companies would choose to do?

**(2) market segmentation of fleets, and**

This question is outside my area of expertise.

**(3) current and planned MD/HD fuel economy regulations in markets around the world?**

This question is outside my area of expertise.

### 4.1-2 Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b? Are the selected technologies suitable as the basis for the analysis?

**Barth**

It seems this question can be answered better from section 3 of the report, not the literature review. In any case, here are the comments:

- Overall, the engines selected for performance analysis seem appropriate. The reason given for the selection is that they are the "most popular engine" in the medium duty class 7 trucks and the low end of class 8. For the larger engine, the selection was again made because the engine is "popular". I believe this is true and don't contest this, however it would be useful to have some kind of table or graph that shows the relative population of the different engine technologies in these vehicle classes (from CALHEAT or from POLK data?).

- On page 25, 3rd paragraph, it is stated that some engine sizes had to be modeled based on recalibrating the GT model for a larger size engine and a smaller size engine. It is unclear how this was done. What parameters were modified in the GT model to do this? How were the results (partially) validated?

- Similarly, the selection of the representative gasoline engines seems appropriate based on what is most popular. Same statements as above apply.

- As for the engine technologies selected for performance analysis, in general the selection seems comprehensive given the description of the technology in Section 2. However, it isn't stated anywhere in the report on how the different engine technologies (and combinations) were selected for analysis. Was there a scientific method, such as principal components analysis on the potential benefits of the individual technologies and their combinations? That could be a starting point, and then the list could be pared down based on technical realism. I think the list is fairly complete, but I suggest a paragraph be added on how the different engine technologies were selected for analysis.

- As for the vehicle technologies selected for performance analysis, again in general the selection seems comprehensive given the description of the technology in Section 2. But again, it isn't stated anywhere in the report on how the different engine technologies (and combinations) were selected for analysis. Was there a scientific method, such as principal components analysis on the potential benefits of the individual technologies and their combinations? That could be a starting point, and then the list could be pared down based on technical realism. I think the list is fairly complete, but I suggest a paragraph be added on how the different vehicle technologies were selected for analysis.

**de Ojeda**

***1. Regarding the selection of the vehicle and engine technologies***

Overall the technologies chosen follow a rather well established criteria of technologies considered in earlier similar studies (NRC, CalHEAT, NHTSA, etc.). No technology presented here is a "surprise" technology but all are well established and recognized. The report in this regards appears in the conservative side.

The study's modeling work does not consider some technologies that are either entering the transportation market in specific segments or are making attempts to enter. The study could have one the one hands gained a *broader scope* and *provided incentives for future directions* of research and developments if it considered:

- natural gas (specially as municipal fleets begin to require a minimum population in their new acquisitions to be powered by natural gas),
- LPG (where significant fleets of school buses are been fit up with these engines),
- Dual Fuel technologies (a significant technology to reduce particular matter when Diesel is used to ignite natural gas, and to reduce fueling cost), and Dual Fuel technologies being available in the retrofit market.
- Alternative Fuels, specially fuels that have the potential in the long run to be viable substitutes to fossil fuels and provide significant advantages towards cleaner burning and simpler engine platforms (simpler fuel injection systems, aftertreatment systems).

Dealing with these areas would enhance the breath of the report. There may be good reasons not to be present in the final count of the technologies to be assessed but these reasons can be given (e.g., owing to the little government endorsement in the US.)

***2. Regarding the process used for the analysis***

The process is adequate. The criteria for evaluation is the percent in fuel efficiency improvement.

The report may have used a criteria that aligns with the GHG and fuel regulations, Grams of CO2 per ton-mile, Gallons per 1000 ton-miles. This approach may lead to technology recipes that match future target standards.

This reviewer would have opted to include an overall summary table or chart providing in the x-axes the vehicle class and in the y-axes the technology package. This would give a clear indication of the applicability of the technologies. In each category (block within the x-y plot) a range of efficiency improvement may be included based on the discussion of the literature review. The above summary could then put into perspective both the technology selection of the report's Section 3 and how the authors' estimates compare with the surveyed literature.

***3. Regarding the range of vehicle models used***

The selection of 5 engine configurations (and two additional "modeled engine versions") appears adequate and well aligned to the selection of four vehicles. The reviewer recognizes the work involved in the comprehensive modeling of each of the vehicle models is *very extensive*. Despite of it, the report is very reasonable in size and reads well.

This reviewer recommends creating a structure to help understand the interface of engine-vehicle-class designation as the report uses different engines for different applications, such as the one given here:

| Class | Vehicle | Diesel | Gasoline |
|---|---|---|---|
| 2a | | | |
| 2b | Ram Pick-up | 6.7 385HP<br>*4.5L model* | 3.5L V6<br>6.2L V8 |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | T270 BOX<br>F-650 Tow Truck | 6.7L 300HP | 3.5L V6<br>6.2L V8 |
| 7 | | | |
| 8 | T700 | DD15<br>*12.3L model* | |

Note that the modeled 8.9L (8 cylinder version model of the ISB 6.7L) appears not to be used in the analysis. It is only described in page 25 but does not appear elsewhere.

**Lowell**

- In general I find the vehicle/engine combinations chosen for this study to be appropriate for the purpose of the analysis and to adequately cover the range of 2b – 8b vehicles, given understandable limitations of available time and money for the project. The RAM pickup, T-270 box truck and T-700 tractor are clearly the three most important vehicles to include, as they fully and adequately represent vehicles responsible for the vast majority of annual fuel use from the medium- and heavy-duty fleet. The rationale for inclusion of the F-650 tow truck is less clear, and I believe it should be explored a bit more in the text. Presumably the T-270 box truck and F-650 tow truck are together intended to represent Class 3 – 8 Urban Vocational Work Trucks, Class 3 – 8 Rural/Intracity Work trucks, and Class 3 – 8 Work Site Support Trucks, in accordance with the CalHEAT market segmentation discussed in section 2.1. I agree that it is appropriate for both of the modeled vehicles representing these segments to be Class 6 vehicles, and that one of them should be a box truck. However, because there is very little discussion in the text about which types of vehicles and duty cycles cover each of these segments, it is hard for the reader to evaluate whether or not the chosen tow truck is an appropriate second vehicle to represent these segments along with a box truck. In particular it would be helpful to understand the importance of PTO driven equipment on vehicles within any or all of these segments, and how/whether for this analysis the tow truck does (or does not) represent vehicles with PTO driven equipment.

- The selected engine models, engine technologies, and vehicle technologies are suitable as a basis for this analysis, and I believe that they reasonably cover the full range of technologies that would be available to improve medium- and heavy-duty truck fuel economy after 2017.

**Midlam-Moher**

The process used in conducting this part of the literature review is not well stated. If the process is felt to be important (which I think it is) then there should be a brief description of the methodology used. For instance, documenting the search terms and the databases used to search at a minimum. Also some idea of the overall goal, such as: 1) Find technologies capable of >X% improvements in the > 2018 time frame; 2) Find at least two credible references for each technology; 3) Included references will be biased towards more recent and more reputable organizations ; *etc*. From this, it would be clear how the technologies reported on were arrived at.

In terms of technologies, I feel that the list serves as a suitable basis for the analysis.

At times, there is a need to better distinguish which fuel certain technologies apply to. For instance, in 2.3.2.1 EGR is discussed. The statement is accurate for Diesel engines but not for gasoline engines which generally have efficiency gains with moderate amounts of EGR. This is more of an issue of technical clarity than accuracy.

**Nelson**

The technologies that have been included in the Class 8 tractor-trailer engine and vehicle analysis are appropriate selections for considering future truck capabilities. Technologies in the study report comprise the primary truck fuel-savings developments identified across the previous reviews by NRC (2010, 2014) and EPA-NHTSA (RIA 2011). The current study also includes the most viable approaches being pursued by the four teams participating in the U.S. Department of Energy SuperTruck projects, summarized by Delgado and Lutsey (2014) (with the exclusion of hybrid solutions which are out-of-scope).

**Nuszkowski**

I was surprised by the lack of combustion related technologies. In Section 3.1.1, Engine Technologies, there is the statement that no combustion related technologies are in the list. Isn't "Stoich EGR" considered an engine combustion technology? In addition, the statement that combustion related technologies only offer benefits of 1-2% is not supported by your literature review. Your literature review mentions benefits of 7.4%, >3%, 7.1%, 3-3.5%, and 4%. Many of the technologies that were investigated involved benefits of 1% or less, so why not combustion technologies?

***Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b?***

The only concern I have is on representing the work site vocational trucks. How was this analyzed and/or rationalized with the vehicles and drive cycles selected? Many of these work site vocational vehicles do not travel many miles and have an engine loading very different than those shown. In addition, engine technologies may be more important in these cases than vehicle technologies.

The description of how the vehicles were selected was only included in the executive summary.

***Are the selected technologies suitable as the basis for the analysis?***

The selected technologies gave a variety of options and analysis.

Many drivetrain options were investigated. Have you investigated the option of a continuously variable transmission (CVT) with high efficiency? Another interesting engine technology is having a variable compression ratio.

## 4.2 Performance Analysis of Technologies

### 4.2-1 Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?

**Barth**

The methodology used for performance analysis of the various engine and vehicle technologies evaluated in this report were of good quality and were sufficiently comprehensive to provide valuable results. There are specific comments about how the method handles transients and other issues in the comments below, but overall I am satisfied with the overall evaluation methodology. The results are meaningful and allow for sufficient comparison between the different technologies.

**de Ojeda**

***1. Comment on the quality, scope, and rigor of methodology used for the performance analysis.***

**Quality** of the report is regarded as high.

Strong points:

- The expertise behind the report. The authors show a deep understanding of engine and vehicle technologies, the impacts of various technologies on efficiency and emission, implications on vehicle installation;
- The very consistent analysis across the engines and vehicles;
- Selection of a wide range of engines and vehicles.

Weak points:

- The number of cycles used add significant information but the report may suffer from excessive numerical output at the expense of not highlighting the more interesting technologies moving forward after 2018.
- There is no cost-benefit analysis such as “pay-back” period.
- There is no fuel efficiency consideration taking into account freight.

**Scope** is very adequate. The study considered a wide range of engine and vehicle technologies, which are listed in tabular forms for each engine and vehicle.

**Methodology** is rigorous. This is illustrated in the systematic approach of adding technology content on the baseline engine and vehicle and reporting the impact on fuel economy.

**Correction and Typos:**

Page 35: “Appendix D… cannot provide the actual ~~the actual~~ input data used in the simulation runs.”

***2. Is the methodology clearly described and appropriate to the aims of the project?***

The method is clearly described in Section 3.2. Specifically:

- Baseline of engine performance is carried out. This is more **clearly seen on the Diesel engines** however where tests and simulations for key parameters are shown side-by-side. This is **not the case for the gasoline engines**.
- The models are run for existing technologies which could be implemented with specified improvements (e.g., improvement on turbocharger efficiency, improvement on drag coefficient).
- The models are also run with new technologies (previously not present on that platform) and very informative discussions are included (e.g., the application of GDI on a PFI style engine, lean GDI, VVA, etc.)

***3. Is it sufficiently comprehensive and robust to provide credible results?***

Yes, the results are in line with former studies (such as the NESCCAF 2009 report).

The report could be enhanced by providing a more comprehensive summary of the technologies. For example the results of engine and vehicle could be combined in a mpg or even better freight efficiency g/mil-ton. Results too could be overlaid with current 2017 EPA standards.

**Lowell**

- The methodology used to evaluate the chosen engine and vehicle technologies was appropriate to the aims of the project, and was clearly described.
- The methodology used to evaluate the chosen engine and vehicle technologies was comprehensive and robust enough to provide credible results.
- One area that requires further description/elaboration is the specific reasoning for the choice of vehicle models used for the analysis, and the choice of drive cycles modeled for each vehicle. Specifically, I believe that there should be text and a table which specifically maps the chosen vehicles and drive cycles to the six CalHEAT vehicle segments discussed in Section 2.1 – i.e., which vehicle(s) and which drive cycle(s) are meant to represent each of the six vehicle segments. To the extent that there is some portion or aspect of one or more vehicle segments that is not addressed by this analysis that should also be discussed briefly.
- Figures showing the speed/time trace for each drive cycle used in the analysis should be included in the body of the report or in an appendix. On page 34 it says that the drive cycles are "described in detail in Appendix C" but they are not.

**Midlam-Moher**

The approach used is credible as it explores a wide range of drive conditions and vehicle states (payload.)

A recommendation would be a limited sensitivity analysis to understand how model calibration errors would propagate through the process. In a project like this that require a great deal of model assumptions and understanding how these effect results is important. I do not think a sensitivity analysis of every single case is likely possible or necessary, however, a "spot check" of a few of the (highest performing?) technologies would be appropriate. I think this would improve the overall conclusions.

The report provides a great deal of data and succinct discussions of each relevant case. I feel that a strong overall summary of the technologies is necessary to provide a clear statement of the efficacy of the different technologies. This could simply be a bar that shows the average impact of the technology on each of the

cycles, average for the highway and city cycles, or some kind of cycle weighted average based on an expected mission profile for the particular vehicle class.

**Nelson**

Refer to comments under question 4.2-3.

**Nuszkowski**

The quality, scope, and rigor were definitely there. Models were extensively calibrated with experimental data when available.

The model was sufficiently described.

### 4.2-2 Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?

**Barth**

- Regarding GT-Power, I believe that this is an appropriate model to simulate engine fuel efficiency. All of the reasons for using a 1-D CFD model like GT-Power are given on page 33 (all of the bullet items), but it would certain be good to have some key references here that back up the various statements. I'm sure that there are some SAE papers and other papers that talk about advantages and disadvantages of engine models and have validation data to back it up, comparing real-world experimental data to modeled data. For example, it is stated that GT-Power gives "fairly accurate representation of overall fuel consumption and CO2 emissions, typically within +-3%". Where is the reference paper that shows that? One or more reference would give this a lot more credibility.

- As a step in between engine and vehicle modeling, speed – load tables are created for 20x20 operating points. It is assumed that all of these points were simulated at steady-state conditions, not transient conditions, correct? I think several of the engine and vehicle technologies being considered in this report might have significant performance differences depending on how the operating points were entered (i.e., from what previous operating point). This is sometimes referred to as a *history* effect; this may not be very significant with fuel consumption performance, but it can certainly have a major effect with pollutant emissions. Can the authors comment on this?

- Regarding driving cycles, there is some reasoning provided in the report that describes why these certain cycles were selected, providing a good range of operations for the different vehicle types. However the reasoning doesn't seem very rigorous. A far better approach would be to examine *vehicle activity data* (i.e., real world trajectory data from subsets of these vehicles) from the vehicles in question, and then select and compare driving cycles that are representative of the vehicle activity data itself. The number of publically-accessible vehicle activity data sets is increasing rapidly and should be utilized if at all possible (e.g., NREL's activity database described at http://www.nrel.gov/transportation). Better yet, rather than use driving cycles at all, why not run entire vehicle activity datasets (appropriate for the vehicle technology) directly through the model(s)? The computational time of these models is not that severe, so processing all of these data should not take too much time. That way you skip any controversy regarding whether the driving cycles are representative or not.

- Overall, I think the modeling methodology using the SwRI Vehicle Simulator tool is sufficient for this study. However, it would be good to have perhaps as a separate appendix that provides a validation run showing how well the model does for a few example cases. You could take a vehicle, measure it on a

dynamometer, then compare the resulting data with the modeled data for the same driving cycle. Through regression plots, you could determine any model bias and model uncertainty. Showing one example of this would give the reader confidence on how well the SwRI Vehicle Simulator tool performs.

- Very minor question: are either the SwRI vehicle simulator tool or the GT-Power model stochastic in any way? Is there any "randomness" that is used as one of the operating variables? This is often done with transportation models to evaluate the true randomness of traffic and to understand different degrees of uncertainty. I assume that there aren't any strong variables that are random in the case of the engines or vehicles and that both of the models used here were strictly deterministic and ran only once per evaluation scenario.

**de Ojeda**

Yes. This reports benefits very much on the work and benchmarking programs that SWRI has conducted on these engines and vehicles. The overall report is highly enhanced by this.

On the engine side, the engines and engine technologies were modeled with GTPower – a well accepted tool in the industry. Baseline models were calibrated with experimental engine data. Combustion heat release data from engine testing were in many instances used. The approach allows for accurate representation of overall fuel consumption and CO2 emissions (typically within +/- 3%) and more accurate representation of small changes in fuel consumption and CO2 as a result of a technology change (within 1%) .

Some limitations exist, particularly in the availability of turbocharger efficiency maps as an input. Actual maps were not available. The simulations employ "generic maps" and use a scaling factor to match the engine flow requirements. This approach is adequate.

On the Vehicle side, the engine maps generated, including fuel consumption, were fed into SwRI Vehicle Simulator tool. This tool handles a wide range of vehicle technologies including automatic transmissions, automated manual transmissions, and hybrid systems, etc.

The following cycles were examined:

For Ram Pickup: FTP City, FTP Highway, US06, SC03, WHVC, 65 MPH
For the T-270 Box Truck and F-650 Tow Truck: GEM Cycles, CILCC, Parcel Delivery Cycle, WHVC
For the T-700 Tractor: GEM Cycles, WHVC, NESCCAF Long Haul Cycle

These cycles are described in Chapter 3 and in greater detail in Appendix C.

**Lowell**

- The models used were appropriate for the analysis and appear to have been correctly applied.

**Midlam-Moher**

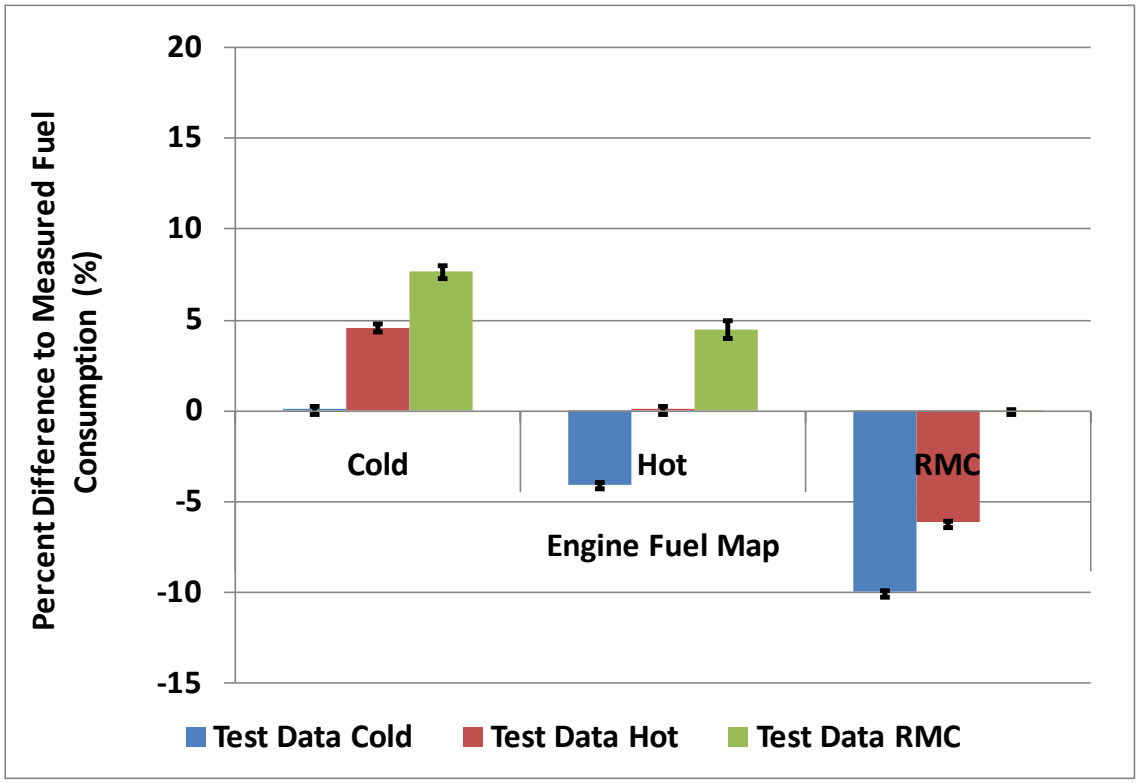
The engine and vehicle modeling approach is reasonable for the scope of the analysis. Like all models, sufficient validation must be conducted in order to have confidence in results. When extending the model beyond the initial calibration, it is doubly important to have good confidence in the model and that the model be of appropriate fidelity to capture the effects of the extensions (*i.e.*, added technology) or modifications (*i.e.,* changing displacement, friction, *etc.*) There are some potential concerns addressed in charge question 4.2-3 regarding the calibration and application of the model – however, the models chosen for the study are deemed appropriate.

**Nelson**

Selection and exploitation of the simulation models used in the study are consistent with those typically used by other published researchers in the field. Refer to additional comments in the response to question 4.2-3.

**Nuszkowski**

Please speak to the transient influence of the technologies and model. The engine fuel consumption maps were based on steady state testing and steady state modeling from GT-Power. Engine technologies, such as turbochargers have a strong transient influence. One turbocharger technology may be better suited for transient cycles than others. Below is a figure showing the influence of an engine fuel map (2010 diesel engine) derived from different test cycle data and then applied to other test cycles. The steady state test cycle (RMC), showed an error of ~5% when applied to a hot cycle Federal Test Procedure (FTP) cycle and ~10% when applied to a hot cycle Federal Test Procedure (FTP) cycle. Did you do any transient test validation or have transient testing validation data?




**Nuszkowski, J.**, Shade, B., "The Impact of using Derived Fuel Consumption Maps to Predict Fuel Consumption," Directions in Engine-Efficiency and Emissions Research Conference (Detroit, Michigan), September 2010.

### 4.2-3 Are the assumptions used in the analysis reasonable? Why or why not?

**Barth**

Yes, the assumptions seem reasonable, based on my own modeling experience. However, to test whether many of the assumptions are valid, you could certainly do the validation testing described above.

**de Ojeda**

Yes. The report provides clear assumptions. There are many examples.

- ✓ The section of Technology #5 (page 41) does an excellent job in showing the assumptions and tradeoffs. The removing of Turbocompounding is discussed in light of the requirement to drive EGR (by means of various pathways such as re-matching of the turbocharger, and addition of an intake throttle) or reliance of heavy SCR for NOx control.
- ✓ The reduced energy content of gasoline with respect to Diesel is explained (such as in page 56) which allows the reader to put in context the thermal efficiency of the gasoline engines when the reports are given in mpg.
- ✓ The important feature of "auto neutral at stop" is very well explained (pages 56-57). This feature absent in a Diesel cycle compromises its fuel efficiency. Representative torque numbers are given as well.
- ✓ For the downspeeding option, the report states that torque curves are increased to provide identical vehicle performance at the lower engine speed. It also points out that the higher BMEP requires upgrades to the engine to tolerate higher cylinder pressure. In practice, as it is pointed out, these are likely to be all-new engines (page 84).
- ✓ The paper makes a very good attempt as to asses the engine out NOx that engine manufacturers will gravitate to (page 88). This is a particularly valuable statement to encourage the research and industrial groups to continue to work on fundamental combustion. As the SCR was introduced there has been a considerable slowdown on this work area, under the assumption that NOx provides efficiency. The brief combustion discussion that follows in page 89 is very appropriate.

There are several areas however noted that the study does not consider in depth but are important and challenging to OEM development teams:

- o Aftertreatment heat management and the fuel penalties associated with them (DPF, SCR units have very strict requirements to maintain exhaust temperatures). This is only touched upon briefly (e.g., page 91) but it is believed to require more attention;
- o Start-up and light off of aftertreatment devices and specially what technologies play significant roles in this area;
- o Weight and packaging of components, with special mention to implications in freight efficiency.

Comments are given below for each section of the report.

<u>CLASS 8:</u>

- The selection of a DD15 engine on the T-700 vehicle (rather than the ISX engine which is what the T-700 actually has) is explained but still lingering to this reviewer it the fact that there is **no model-to-hardware true benchmarks** of the actual vehicle-package. For example, the fuel economy number of figures 3.2 and 3.3 are not compared with real world numbers.
- The authors could have included turbo-charger **VNT technology**, though this may have been "inserted" under Technology 12 – higher efficiency turbo.

- The discussion on removal of the APT unit, and the removal of the APT and EGR, show a reduction on pumping of approximately 0.5bar across the lug curve. Nevertheless the BSFC remains nearly unchanged. A change of 0.5 over 17 is approximately 3%. Where may this be going?

- The discussion on *weight distribution* is given significant treatment and can be followed well (page 50). The *resistance values* associated with these are not explained however (at least this reviewer did not follow). Maybe this can be done in the revised version.

- Little discussion is given to **weight of the technologies** (e.g., in the waste heat recovery), where as **freight efficiency** should have been addressed.

TYPOS:

- page 48: *These results are shown in Figure ~~3.6~~ 3.7 below*.

- Page B-14, B-16, B-18, B-22, B-36: GROSS IMEP on figures should read PMEP.

RECOMMENDATIONS:

There should be a study funded on VVA technologies for Diesel engines. This technology is largely omitted in the report given the poor understanding of the impact of the technology on the engine performance.

<u>CLASS 6 (Kenworth T-270 Delivery Truck):</u>

- Whereas the modeling results for the Diesel engine baselines are well documented in Appendix B (includes experimental vs. model results of key parameters such as BSFC, pressures, temperatures, flows), the **gasoline engines in Appendix A are not benchmarked**. Would the authors be able to update the report with a similar treatment?

- *Section 3.3.3.1:* When discussing the base engine technologies a **summary table** that includes the ISB, V8, and V6 engine performance (best BSFC point, peak and rated TQ and speed) may prove to be helpful. It may include salient technology contents as well, as CR, fuel system, air system, EGR, turbo.

- *Section 3.3.3.1:* The reports in this section are given in mpg comparisons. Would the authors consider providing the **results in BSFC** (in addition to what is presented) for a engine evaluation/comparison?

- *Section 3.3.3.2:* May chose to **bold the V6 and V8 comparison to the baseline ISB** on table 3.17. It will help to asses the relative contributions of the following technology additions.

- *Section 3.3.3.4:* The **selection of 10 to 35% friction reduction** (at high and low loads respectively) needs better treatment on Appendix B (page B-33). This particular section could list technologies that contribute to the values chosen.

- *Section 3.3.3.9:* For the lean burn GDI, is it possible for the report to be more specific as to how much **pumping losses and spark timing** contribute to the gains presented? These settings may be included in Appendix A (near page A-10). Were other contributors part of this gain, such as reduced heat transfer?

- *Section 3.3.3.9 and 3.3.3.15:* **What temperature values were selected** to allow for optimum aftertreatment durability and conversion efficiency? How accurately is the GT power modeling regarding exhaust temperatures? Appendix B-40 shows 25 to 50C deviation for the ISB case.

- *Section 3.3.3.10:* What is the effect of added EGR on combustion efficiency and would this affect the efficiency numbers presented here?

- *Section 3.3.3.14:* The statement that "The benefit from the compression ratio increase is partly offset by a reduction in **combustion efficiency**" is not clear and may not be accurate. Authors may want to explain or reconsider statement.

- *Section 3.3.4.2:* The reduction in Cd of 15% may be further elaborated in Appendix C (page C-13). **What are the technologies that contribute** to this reduction? Can these be inserted in the Appendix?

TYPOS and CORRECTIONS:

- page 61: "in this case, 600 to ~~6,000~~ 5,500RPM". [Data in appendix reports 5,500rpm for the V6 engine).

<u>CLASS 6 F-650 Truck:</u> This section follows closely on T-270 Truck discussion. Same comments apply here as to the earlier section. Addressing these on the T-270 section would be sufficient.

TYPOS and CORRECTIONS:

- *Section 3.3.5* Page 69: The first paragraph is identical, and the following one nearly identical, to that of page 54. May read better if referenced to the earlier section.

- *Figure 3.24* shows the Y-axes and title overlapping. Please correct.

<u>CLASS 2b-3 Trucks - Ram Pickup Truck:</u> This section too follows closely the CLASS 6 sections.

- *Section 3.3.6.2* Page 82: The discussion could be improved by making explicit references to the engine under consideration. The discussion on each of the engines follows the figures, but the text could be more explicit stating what engine is being discussed.

- The paragraph starting *"As with the medium duty vehicles…"* in page 83 should start by making reference that the discussion pertains to the V8. The later "large engine" would be better understood.

<u>TRADEOFF BETWEEN FUEL CONSUMPTION AND CO2</u>: This portion of the report is short but very informative. The report could be improved by adding:

- Representative fuel **usage required by SCR and DPFs** (fuel required to maintain the functional minimum temperature requirements, fuel required to bring the DPF to temperature on typical regeneration events), including the estimation regeneration duty cycles associated with the drive cycles selected here (page 86).

- It is unclear why the tradeoff study is focused on the larger vehicles only (page 86). Could this be **extended to MD sector**?

- The discussion on the 0.2gNOx engine out NOx needs to be **properly referenced**. The response of NOx to BSFC will depend much on the technologies that the engine bears, such as fuel injection pressure range, close coupled injections, the air and cooling system, the combustion bowl-to-injector match, etc. (page 86). The 20% appears to be too large of a number for the reader to walk with. Data is available from the DEER meetings by Cummins, CAT, and Navistar that show less of a gap, and a gap that depends on technology content.

- The discussion on Key Limiting Issues (page 88) is excellent. The authors on point 1 make a very revealing comment regarding the best engine efficiency point versus the "real world" operation point or the "regulatory cycle point". The paper could **further elaborate** on this, specifically, how to limit the gap between the second and third, the first, being more of the OEMs effort to align engine and vehicle modes of operation.

***Point of Clarification***

This discussion is particularly insightful for it concerns the real-life implementation of technologies.

Here the authors raise three areas that are very relevant: First, that a best efficiency point may be attained that does not correspond to where the engine typical operates, nor correspond to where the emission certification evaluates the engine. Secondly, the best efficiency point may compromise the product requirements. Thirdly, the authors gives notice of the monitoring requirements from OBD (see page 88).

The first point is clear, in that the best efficiency point is relevant in as much as it corresponds to the drive cycle experienced in the application. The importance of the emissions certification matching the duty cycle is equally important and it deals with it in a separate section of the report.

The second point, is particularly important as studies of technologies have demonstrated fuel savings but have "relaxed" the engineering constraints that would in many cases prevent a manufacturer from implementing the technologies in their product. The example of NVH is one. Other examples are "very high combustion pressure" regimes (compromise the cylinder head, crank case, bearings), very aggressive VVA settings (compromise combustion stability), etc. It is important that these studies clearly highlight the "reasonable" margins of operation. As the authors evaluated technology options, they in many instances referred to possible compromises.

Lastly, the OBD requirements will indeed require special attention as exemplified by the high SCR efficiency that would be needed in the case of very high NOx combustion modes.

**Lowell**

- The assumptions used in the analysis appear to be reasonable.

**Midlam-Moher**

On A-2, the data used to calibrate the 3.5L engine is listed as six signals. This list is quite short and is missing some key parameters, such as throttle. The same concern exists for the other three engines. I assume this is an oversight – if not then some explanation needs to be given on the approach. In the validation plots, agreement in air mass is required to demonstrate model accuracy. The quality of the air agreement of the model is not specified, only that it was "close to the experimental data." With the approach taken, adjustments to the heat transfer model could very easily mask significant errors that have a root cause in issues with the air modeling. This would weaken conclusions made from the model. The same comments exist for A-17, section 2.1, regarding the baseline V-8.

On A-10, there is insufficient information to evaluate the approach to developing the GDI engine model. There is no discussion in particular of how the stratified charge mode would be handled from a combustion perspective. There is also some optimization that needs to occur for the mode transitions and within the mode regarding AFR which should be discussed as well.

On A-12, there is insufficient information to evaluate the approach in modeling the HEDGE. Some "rule-based" guidelines are provided for modifying the combustion model the basis of which is not provided. The same argument applies to EGR selection and cam phasing. I understand that fully modeling this is outside the scope of the work, but there needs to be additional explanation and a validation that demonstrates that the

assumptions led to results comparable to experimental work. The same comments here apply to section 2.3 on A-20.

The approach used in Appendix section 1.2, 1.3, 1.6, 1.7 and 1.8 appears sound given the constraints of the study.

On A-19, section 2.2, the approach used regarding modeling of the GDI engine is not described in sufficient detail. I understand the limitations of GT-Power and difficulty in modeling combustion, however, the assumptions made are not backed up by any data. What is the added pump load and why? Why decrease combustion efficiency by precisely 2%? Furthermore, the resulting BSFC map without any kind of validation. I would think it possible to cite a reference that says you should get a ~2% change in BSFC on average (or whatever your target is.) The approach used in section 2.6 (A-25) requires the same type of justification.

The approach used in Appendix section 2.4 and 2.5 appears sound given the constraints of the study.

The approach used in section 2.7 (A-27) needs some basis for the friction reduction. Why is a reduction of 10% FMEP a valid number? This should be explained.

Figure quality in B1a and B1b (B-4) is poor.

In 1.1 (B-3) the accuracy of the air agreement needs to be shown in addition to the BSFC error. With this type of model it is easy to match torque independently of air by altering heat transfer, friction, *etc.* This comment is similar to that stated previously with the gasoline engines.

The approaches used in appendix B appear valid provided the baseline model is accurate. The changes described are all consistent with the capabilities of this class of model and should yield appropriate results. There is not a great deal of info provided on many of these so it is difficult to truly ascertain the validity of the approach without going into great detail – but I have no reason to doubt the approach and execution from what is presented.

**Nelson**

**Tire rolling resistance from coastdown measurements.** Tire rolling resistance inputs to simulations have been obtained from coastdown testing for all study vehicles using SAE J1263 method (directly or with modifications). Coastdown tests are routinely used to calculate the coefficient of aerodynamic drag (Cd) and tire Crr as inputs for chassis dynamometer tests and vehicle simulations. However, there can be difficulties with data obtained in this way for a couple of reasons. First, and the most minor, is that other friction and drag effects can be rolled into the value of Crr. Second, conditions of the testing, and the speeds at which the data is acquired, can have non-negligible influence on both Cd and Crr (Hausberger, 2011). And finally, it can be difficult to relate coastdown values of tire Crr to those measured on a laboratory test drum under controlled conditions, as discussed below.

When tire rolling resistance is measured on a test drum, the curvature of the drum generates greater deformation of the contact patch and thereby increases rolling resistance relative to the level that would be experienced on a flat surface. Using the formula developed by Clark (1976), the Crr value obtained on a curved surface can be adjusted to flat ground or to any other diameter test drum. The formula:

$$Crr\ (drum) = Crr\ (flat) * [1 + (R(tire)/R(drum)]^{1/2}$$

predicts that a truck tire of 0.5-meter radius would have a rolling resistance level approximately 20% higher on a 1.7-meter diameter drum than on a flat surface, where R(tire) is the unloaded nominal tire radius, and

R(drum) is the radius of the test drum. There is some uncertainty in the "true" level of the correction factor predicted by this formula.

Furthermore, there is some speculation that the predicted change in absolute rolling resistance that is observed in going from a laboratory drum to flat ground may be approximately compensated for by increases in rolling resistance associated with road surface roughness. In the case of the Hausberger study, tire rolling resistance coefficients did increase in going from drum measurements to track tests, and not necessarily in the same proportion by tire type. It was also concluded that drum measures of Crr were likely to be necessary to generate appropriate coastdown values for Cd.

Tire Crr from coastdown testing aggregates the effects of steer, drive, and trailer tires into an overall effective tire rolling resistance for the entire vehicle. This is a useful approach for simulation, easing the burden of modeling Crr effects individually by axle. But good data for Crr (and Cd) are critical for the vehicle simulations. The values used in the report may be completely correct, but it is difficult for the reader to make this assessment without: 1) greater explanation of the testing than is given in Appendix C, including whether the tires used were new, partially worn, broken-in, etc.; 2) laboratory measurements of Crr for the tires used on the study vehicles by tire type; and, 3) some selected comparisons of experimental data from whole vehicle road tests with simulations of fuel consumption/MPG shown in the Tables 3.11 and 3.12 (T-700), 3.15 and 3.16 (T-270), 3.19 and 3.20 (F-650), and 3.22 and 3.23 (Ram). This last item would validate both fuel consumption in terms of an absolute value, and more importantly, also validate the slopes of the curves in Figure 3.8.

The linear form of the relationship between ΔCrr% and ΔFC%, by drive cycle, with different slopes according to the drive cycle used, has been demonstrated in the past (LaClair 2005). If the confidence is high regarding the values of the slopes, then knowing the *change* in Crr (ΔCrr) between two tire sets is much more important than having the absolute values of Crr. *Relative* changes in fuel consumption can then be predicted from *relative* changes in tire rolling resistance. See also Barrand and Bokar (2007) and Guillou and Bradley (2010).

Lastly, the text in Appendix C, Section C2.3 reads as follows, but no separate Crr data by tire type is provided.

> "For the tractor-trailer vehicle, separate Crr values were used for the steer tires, drive tires, and trailer tires. For the medium-duty trucks, separate Crr values were used for the steer and drive tires."

**Nuszkowski**

There were many assumptions applied during the study and they seem reasonable. The most important assumptions (Tables 3.1 – 3.9) were the assumed reductions in drag, rolling resistance, chassis friction, and engine friction. Are these numbers based on references? The reader will assume these are achievable reductions.

### 4.2-4 Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.

**Barth**

In general, the findings and conclusions are adequately supported by the simulation results. Some general comments are as follows:

- The commentary about the variable valve lift technology for this diesel engine at the bottom of page 38 seems strange. If a few operating points were analyzed and used to determine that the technology doesn't perform that well, how do you know that the technology doesn't perform better at other operating points? This either needs better explanation, or the full analysis should be completed. Just because the savings are small isn't a good reason to exclude it; other technologies in table 3.13 show small savings of 0.1% (e.g., technologies 10 and 11).

- For completeness, it would be good to repeat figure 3.4 for not just 50% payload, but also for the other payload set points.

- Section 3.3.1.14, it isn't clear what is meant by stating "making OBD very challenging", I think the authors mean that the emissions control system design for aftertreatment is very challenging, right?

- For technologies 17 and 18 (sections 3.3.1.17 and .18), it would be good to illustrate the results here for the different payloads. It seems very logical to downsize an engine, but then realize that the performance of the vehicle drops off (e.g., acceleration rates, etc.). With the lower acceleration rates, was the vehicle model able to keep up with the target speeds of the driving cycle? Were there some of the configurations (e.g., large engine downsizing, high payload, aggressive cycle) where the vehicle could not "follow" the driving cycle? If so, how did you carry out the simulation? Was the drive cycle simply extended, or was it cut short? This has a large implication on what the final fuel consumption reductions would be.

- Similar to figure 3.4, it would be good to repeat figure 3.5 for not just 50% payload, but also for the other payload values. This is particularly true where later in the report it is stated: "fuel savings offered by most vehicle technologies is very duty cycle and payload dependent".

- For section 3.3.2.4, the weight issue makes perfect sense. However, won't truck operators in many cases increase their payload to max out their weight for economic reasons, thereby negating any weight loss gains?

- For the speed governors, this was only evaluated for a single cycle that obviously had vehicle target speeds above the speed governor set points (55mph and 60 mph). It is not clear how the cycles were actually applied in the simulation runs when the simulator could not hit the "target" speeds of the cycle. Was the rest of the cycle played out to the end, or was the cycle truncated? Was the cycle completed on a time basis or on a distance basis? Based on the discussions of the longer trip times, I assume the cycle was played out until the end. These are very important issues in terms of determining the final fuel savings. In the real world, the trip still needs to be complete, so the evaluation should be completed on a distance basis, and the overall fuel economy should be calculated for the entire trip. The authors point this out to some degree, but this could use some more explanation.

- It would be good to repeat figures 3.13, 3.14, and 3.15 for not just 50% payload, but also for the other payload values. We want to see sensitivity analysis based on payload differences. If there are very little differences, then state so.

- In section 3.3.3.18, when the downsized engines were run for the more aggressive cycles with grade, the vehicles cannot follow the cycles; similar to previous questions, how did you handle the remaining part of the cycle in the evaluation run? It makes a big difference in the results.

- In section 3.3.3.20, it is stated that the technology is only applied to certain cycles that long steady-state components, since the response to other cycles is minimal. But why not run the evaluations for these other cycles, just to show that the technology is not effective? How was the transient response handled when the modeling approach is essentially "steady-state" in nature? Were there time constants and

other thermal parameters involved? I think the modeling approach on this technology needs a bit more explanation.

- For section 3.3.3.21, same comments/questions as above.
- For section 3.3.2.1, is the AC cycled? Or is it assumed to be a constant load throughout the cycle in question? In the real-world, the AC compressor will cycle depending on temperature and humidity involved. I'm not sure if this will make much of a difference in the results.
- The authors mention the tradeoffs between weight reductions, and increases in weight with possible increased payload. This is certainly true that carriers will try to maximize the economics of moving goods, so any down-weighting will likely be replaced with increased payload weight.
- For table 3.24, for the cycles that weren't able to complete, see previous comments/questions about how were the simulations completed in those cases.
- I like the discussion of section 3.4 on the fuel economy and NOx and PM tradeoffs. This will always be an important issue as the NOx and PM standards get progressively more severe. In the analysis, I didn't see any mention of specific future NOx and PM emission standards with specific numbers. Why not use those more restrictive numbers in this analysis, especially when looking at future fuel economy standards? I think the text discusses this in general, but I didn't see the specific numbers.

**de Ojeda**

The report is very thorough, systematically listing the findings per technology. The report focuses on the quantitative assessment of technologies across engine and vehicle. During the narrative, the authors make insightful remarks pertaining to each category. The report however does not provide conclusions or 'final remarks'.

For example, the authors make significant remarks to understand the context of the technologies examined. *This contribution and its importance to industry and regulators cannot be undermined.*

- It cautions the reader in several instances of the implications rendered by removing the EGR loop, where the result of reducing the pumping losses will need to be assessed with very high NOx output from the engine and the greater requirements expected from the aftertreatment systems.
- Identifies current cost comparisons between the MD diesel and gasoline engines (e.g., in the case of the F-650 Class truck, approximately $9,000), and the issues with the application of gasoline technologies onto more severe applications.
- Similarly, the authors present the implications of E10 on fuel consumption penalty.
- Many other examples are cited.

However, as noted, there are *no conclusions section in the report*. The report should include a conclusion section, different than the summary provided in the executive section. Oftentimes reports limit the conclusions by summaries of the findings (such as done here in the Executive Summary), but we hope the authors can provide more value by synthesizing conclusions, a verdict on the technologies assessed.

**Lowell**

- The findings and conclusions are adequately supported by the data.

**Midlam-Moher**

I have no reason to disagree with conclusions made in this section of the report. Per comments above, I do feel that there could be a greater level of validation provided to give greater confidence in the ability of the modeling approach to yield accurate results.

**Nelson**

Elaboration of the derivation of Crr and supporting information should be provided as discussed in question 2-3. A more thorough summary of vehicle simulation comparisons with chassis dynamometer data across the baseline vehicles would reinforce the credibility of Appendix C.

**Nuszkowski**

The findings and conclusions are supported. Was there analysis (propagation of error) done on the model accuracy in regards to the influence in the percent error of the model to the percent error in the fuel consumption reduction? This may provide a guideline to what is considered a significant reduction in terms of percentage by your model.

## 4.3 Evaluation of Testing and Simulation Approaches

### 4.3-1 Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.

**Barth**

Section 4 is well written and touches on all the key issues. I believe it adequately addresses and summarizes the different fuel efficiency metrics and engine efficiency test procedures. Some specific comments:

- It is stated that "A dynamometer test on an appropriate duty cycle is a more reliable way to determine efficiency". In line with some of the earlier comments about modeling methodology, there is now a big push to get away from duty cycles (because of the issues of whether they are always appropriate) and to do more in-use measurements in the real-world. We have the technology to measure overall performance and to aggregate the performance data and record and evaluate it (overall, this falls into a "Big Data" scenario). So why not put the engine and technology in place, measure the performance for a wide range of uses, and then use those numbers to set new standards in subsequent years? The details of this needs to be fleshed out, but the trend is to get away from dynamometer testing. The middle paragraph on page 101 touches on this a bit.

- On page 97, it is stated that "we recommend that it be left to manufacturers to develop approaches for validating the performance of fuel saving technologies that fall into this realm". I would be a bit wary about letting the manufacturers do the validation, the nature of the manufacturers is to maximize economics and that sometimes that gets in the way of proper testing.

- The discussion on hybrid technologies is another wrinkle in the evaluation methodology, I assume this will be addressed more fully in subsequent reports. But this just goes to show you that an in-use evaluation approach mentioned above will also work well with hybrid technology.

- On page 99, "Driver reward systems" are part of the eco-driving techniques mentioned in the general comments below, which should be considered, but seem to fall outside the scope of this analysis.
- On page 100, it is mentioned that OEMs have very sophisticated tools that are routinely used to optimize specifications for customer applications; why not optimize these parameters in real-time based on vehicle performance, to the extent possible? I wonder if some discussion can be made on these "learning" techniques that can be applied to engine and vehicle operation.
- Overall, there is very good coverage on the international standards work, in many ways, this covers the comments I made earlier.
- I like the discussion on the payload sensitivity, and the drive cycle sensitivity. This section addresses in part some of the comments and questions made above.

**de Ojeda**

***1. Adequately review relevant fuel efficiency metrics that take vehicle work and use into account?***

The report attaches on Table 4.1 the "type of regulation" and the "metric" used. The table would be more informative if also included the requirements (values). **Suggested references**: Regulatory Document 40 CFR Part 1037 (e.g., show the requirements per Table 1037.105-6 for Vocational Vehicles and Tractors).

The discussion that follows is informative, as it illustrates the disadvantages of the miles-per-gallon metric (it is a not linear metric over a range of fuel mileage and is correlated one-to-one with fuel consumptions).

Metrics for units of work are discussed, including ton-mile, passenger-mile, and cubic-volume-mile. A practical example is used to illustrate the payload effect in a long combination vehicle. Later in this section, the report concludes with a revisit to the simulations of Section 3 with an emphasis to show the dependency of technologies on both drive cycles and payload. The discussion is particularly insightful to show that some technologies have a large dependency on these two parameters.

This reviewer agrees with the assessment that the metric of gallon/100 bhp-hr may not be the most adequate and may not be an improvement over the earlier metric of g/bph-hr. **Suggested reference** to be placed in the text at this point is the Federal Register Vol. 76. Sep 15, 2011, Rules and Regulations (page 57141). A web link will be useful.

***2. Engine efficiency test procedures, vehicle efficiency test procedures***

The engine efficiency test procedures are covered well by subdividing them in three categories, (1) technologies where the current tests certification procedures do well, (2) technologies where too small of an impact would compete with the uncertainty of the of the certification tests, yet an estimate can be made via accurate bench testing (e.g., oil pumps) or modeling (e.g., adding a clutch in an air compressor) and (3) specific technologies that would not appear on an engine-only certification, the example provided here is downspeeding.

A side comment – in the realm of HD engines the application of variable water pumps and oil pumps can be significant and its impact recorded in the certification cycle. The report may state that these technologies can be lumped into category (1) above. **Suggested references**: Same as used in the literature review on these components by Daimler and Navistar.

The vehicle power demand section describes the GEM model and its inputs. The report offers particular insight of VSL and AES to real-world application. The discussion continues to technologies that are not

directly captured in the GEM model. As with the engine discussion, many of these technologies can be benchmarked on dedicated stands to calculate the fuel savings.

Section 4.4.3 deals with SET test points. The data represented in this section from a VOLVO sample of HD long-haul trucks is very informative but needs to be better described and put in the greater context of other manufacturers. The data reflects a significant downshifting. There are many HD applications that will show a different histogram (inter-city, hills, mountains, etc.)

The SET test points are in principle a good and simple approach to estimate the overall power plant efficiency. This reviewer agrees that the right weights need to be updated. Engine and vehicle engineers oftentimes asses drive cycle fuel economy with specific weights to each point according to the drive cycle their vehicles operate in.

Similarly Section 4.5.2 which deals with the FTP test points. The report shows another sample of VOLVO vocational trucks. The data is informative but it would be best to have a wider sample from other manufacturers.

***3. Efficiency simulation approaches?***

Several thoughts come from the information provided in this section:

One is the opportunity to provide tools to customers, be it large or smaller fleets, to optimize the specifications of vehicles, similarly to what OEMs have developed. Rather than stand-alone, these tools could be tied into the regulatory process to better match engine rating, transmission type, axle ratio, payloads typically used, drive cycles driven.

Second, is the introduction of accurate instant and 'averaged' fuel performance estimates by the vehicle. Its implementation would need to be studied in detail, especially when needing to update the load of the vehicle. This could be expressed as stated in the regulations (e.g., grams CO2/ton-miles or gallons/ton-miles for the vehicle or per bhp-hr for the engine). This may be done with accurate flow meters or a reliable fuel map tables (which may not be always very accurate).

TYPOS:

Page 98, * CFD analysis, or [Constant speed testing]

Page 98, • ~~Constant speed testing~~ Steer…

Page 100, routes where smart ~~of~~ [or] GPS-based cruise control

Page 102, Section ~~7.2~~ 4.2

Page 103, Section ~~7.2~~ 4.2

Page 105, were evaluated in Section ~~5~~ 4.2.2

Page 111, the ~~FPT~~ FTP cycle clearly over-represents

**Lowell**

*(1) Fuel efficiency metrics that take vehicle work and use into account*

- This section adequately reviews, summarizes and presents available data on fuel efficiency metrics

*(2) Engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.)*

- The discussion of "power pack testing" on page 97 indicates that "The powertrain test cycle would include specification of the powertrain output shaft speed and torque as a function of time, to simulate a given vehicle drive cycle chosen by the regulators". While I agree that power pack testing is a relevant and useful method for certifying certain technologies, it should be noted that there are no generally accepted "powertrain test cycles" that correspond to any commonly used drive cycles such as those used for modeling in this project. While development of such a powertrain cycle is conceptually straightforward it would require making a number of assumptions about vehicle configuration, including power to weight ratio and transmission and rear end gear ratios. The use of different assumptions for these parameters would result in different shaft speeds and torques as a function of time. One might need to develop a series of powertrain cycles corresponding to different types/configurations of vehicle operating over the same drive cycle.

- In sections 4.4.3 and 4.5.2 the authors recommend that EPA and NHTSA re-evaluate the use of the SET and FTP engine test cycles for certification of compliance with engine fuel use and GHG standards, in order to better match average in-use engine performance. While I do not disagree with this recommendation, I believe that the discussion should highlight the fact that these test cycles were chosen by EPA and NHTSA specifically to maintain a direct link between criteria pollutant and GHG certification test procedures. Breaking this link would create the potential for negative, unintended consequences and in my opinion would not be advisable. I would suggest that the appropriate recommendation would be for EPA to re-evaluate the use of SET and FTP for both criteria pollutant and GHG certification, but to maintain common procedures and test cycles for both.

*(3) Efficiency simulation approaches*

- In section 4.5.1 the authors highlight some vehicle technologies that are not currently captured in GEM for vocational vehicles, but which could be used to further reduce fuel use from these vehicles. Several of these technologies could be simulated by GEM without structural changes to the simulation model (weight reduction, Cd reduction) but most could NOT. GEM specifically cannot simulate the effects of the most promising approaches (AMT, neutral idle, reduction in parasitic loads). The authors should make recommendations for how GEM should/could be modified to account for these technologies and/or offer thoughts on alternative certification approaches.

**Midlam-Moher**

Fuel efficiency metrics that take vehicle work/use into account: The report does not succinctly or cohesively describe fuel efficiency metrics that take vehicle work/use into account. It contains uncited statements and informal language like, "Twenty years ago, almost every driver did upshifts only as the engine approached the high-speed governor." (page 100) It does bring up a good number of real difficulties in developing metrics but does not offer much in the way of direction. I feel that there is a great deal of good information here but it is not presented in a way that strongly supports the goal of the report.

Engine/vehicle efficiency test procedures: There is a general review of engine/vehicle efficiency test procedures. It would be helpful to have an additional section that summarizes the approaches from each of the regulatory groups discussed. As it is, the information is relatively diffuse and future readers could benefit greatly from an overall summary comparing/contrasting the different approaches.

Engine/vehicle efficiency simulation: There is not a strong discussion of engine/vehicle efficiency simulation approaches. This issue is dispersed throughout the section and not dealt with in great detail. I would recommend a separate section be devoted to this and relevant information pulled into it and summarized. Of particular interest would be the type of models used and how they compare to something familiar in the US like GEM.

Overall: This section is not as well-written as other parts of the report. It has a lot of good references and discussion but could benefit from being refocused on the specific tasks.

**Nelson**

**Metrics.** The trucking industry has internally tracked a number of key performance indicators (KPI) such as tons of freight moved per year, vehicle miles traveled (VMT) per year, total quantity of fuel consumed per year, proportion of empty miles, miles per vehicle per year, as well as very familiar-sounding KPIs including ton-miles per year, ton-miles per vehicle per year, cost per ton-mile, and cost per ton-hour. Just as ton-miles per year is an indicator of annual freight carrying productivity, an indicator like load-specific fuel consumption (ton-miles per gallon, or the inverse for fuel consumption, LSFC) is an analogous measure of freight efficiency. LSFC should continue to be an appropriate metric.

Alternatively, would it be better to include the weight of the vehicle together with payload in the tons calculation of LSFC? If we apply LSFC based on payload, then a less-than-truckload (LTL) fleet would be ranked as much less efficient than a truckload (TL) fleet, even though the cargo area of the LTL carrier is full. The effect of including vehicle weight would reduce (and sometimes significantly) the difference in efficiency ranking between the two fleets versus payload-only based comparisons. In addition, including vehicle weight as well as payload reduces the efficiency difference in comparisons between classical tractor-trailers and long combination vehicles (LCV). This could make LCVs appear less attractive because the scale of LSFC comparison is smaller. This comment is for reflection only, the current LSFC metric of gallons/1000 ton-miles should function appropriately whether the vehicle weight is included in the load calculation or not.

In the commercial sector, using LSFC as a metric for rulemaking and MPG as a familiar metric by end users may not present such a difficulty. Truck fleet managers are very cognizant of their freight patterns, equipment, and costs of most aspects of their operations. Often, fleets divide their businesses into “sub-fleets” of similar usage characteristics to be able to optimize and track specific types of applications. They are generally able to properly assess changes in MPG in the context of their own operations.

**Drive cycles and technology performance.** Given all the background information available on the topic of drive cycles, I am only able to add a couple observations here. First, it is outstanding to see a consistent analysis work method applied to illustrate the relative strengths and weaknesses of key technologies across a range of familiar drive cycles. In fact, in my view Section 4.6 is the most impactful section of the report.

How these results can be incorporated into GEM is a challenge. The second point is that there should be an explicit statement of the requirements for a drive cycle, or combination of drive cycles, within this regulatory context. Should a drive cycle be the best possible representation of a particular vehicle’s real-world operation? Should it be able to be reproduced in chassis dyno tests as well as on a track or roadway? Should it highlight or mask the effects of particular technologies? Is it acceptable to piece together discrete fractions of usage conditions of existing drive cycles to create an entirely new series of vehicle operating steps for simulation? The “best” strategy for GEM may not necessarily be the best strategy for other purposes such as vehicle or technology design.

**Trailers and drive cycle weightings.** An example of how the trailer tires contribute to the overall effective vehicle rolling resistance (which we might also say is the coastdown Crr of the vehicle) is shown in the

following table for estimated axle loads for the T-700 for the 0%- and 100%-payload cases. The effective vehicle Crr(veh) is given as:

$$Crr(veh) = [\ \Sigma_j\ Crrj * Zj] / [\ \Sigma_j\ Zj\ ]$$

where, for this case Crrj is the coefficient of rolling resistance on axle j, and Zj is the total load on that axle. The table shows the role played by the trailer axles in percent of load carried, and percent contribution to the total rolling resistance of the vehicle for the two payload cases. Example tire rolling resistance values are current SmartWay thresholds for steer, drive, and trailer tires. In the zero payload case, it is assumed that the steer axle carries 11000-lb, that the 15000-lb trailer weight is split evenly between the drive and trailer tandems, and that the drive tandem carries the balance. If all tires on the vehicle have the same rolling resistance, then Crr(veh) = Crr(tire). If the tire rolling resistance is different by axle position, as is common, then the percent of weight carried by the axle does not necessarily equal the percentage contribution by that axle to the overall Crr(veh). In this latter case, the value of Crr(veh) depends on the weight distribution by axle (as well as the steer, drive, and trailer tire Crr values).

| Description | Steer Axle Weight, lb | Drive Tandem Weight, lb | Trailer Tandem Weight, lb |
|---|---|---|---|
| ***0% Payload case, Total vehicle weight 33960 lb.*** | | | |
| **Load distribution of empty tractor-trailer*** | **11000** | **15460** | **7500** |
| **% weight carried by axle or tandem** | **32%** | **46%** | **22%** |
| **Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)** | **6.5** | **6.6** | **5.1** |
| **Rolling resistance contribution of axle to Crr(veh), kg/T** | **2.11** | **3.00** | **1.13** |
| **Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T** | | **6.24** | |
| **% Contribution of axle, tandem to total effective vehicle Crr(veh)** | **34%** | **48%** | **18%** |
| | | | |
| ***100% Payload case, Total vehicle weight 80000 lb.*** | | | |
| **Load distribution of 46040-lb payload tractor-trailer** | **12000** | **34000** | **34000** |
| **% weight carried by axle or tandem** | **15%** | **43%** | **43%** |
| **Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)** | **6.5** | **6.6** | **5.1** |
| **Rolling resistance contribution of axle to Crr(veh), kg/T** | **0.98** | **2.81** | **2.17** |
| **Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T** | | **5.95** | |
| **% Contribution of axle, tandem to total effective vehicle Crr(veh)** | **16%** | **47%** | **36%** |

*** Assuming steer axle weight does not vary greatly due to engine weight on axle.**

When aerodynamic optimizations are made on the tractor only, some technologies may add weight, but many improvements to bumpers, mirrors, or existing roof fairings could be accomplished at nearly iso-weight. On the trailer, aero packages can add up to 2200-lbs (Delgado and Lutsey, 2014), or approximately 6.5% of the tractor-trailer weight (without payload). Accounting for both improved Cd and increased weight of aero technologies on trailers slightly reduces the effectiveness of obtaining fuel savings on the 65 MPH drive cycle shown in Figure 4.6. Combining aero and its intrinsic weight on the CARB cycle, shown in Figure 4.7, results in a negative contribution of that technology to fuel savings. The impact may be small due to the small weighting factor of the CARB cycle in GEM for tractor-trailer combination vehicles. But it highlights an example scenario where some technologies may have fuel disadvantages in certain specific applications, but

also raises the possibility that those technologies may still be included in regulatory equipment packages due to overall benefits.

Most large fleets using box van trailers have an equipment ratio of about one tractor to every three trailers. Trailers generally accumulate miles much more slowly than tractors – perhaps 25,000 to 35,000 miles/year versus an accumulation of 100,000 miles or more annually for tractors. It will take longer for a fleet to realize its full return on investment for a trailer technology than a tractor technology, even though fuel consumption and GHG improvements are observed on a national level.

**Nuszkowski**

This section gives a very good review of fuel efficiency metrics, test procedures, and simulation approaches. There wasn't any discussion on the accuracy of each method of testing and simulating. What could be the achievable accuracy of the different test methods and how significant does the change in the fuel efficiency metric need to be for chassis testing versus engine testing versus a test bench vs simulation? Accuracy was only briefly mentioned when discussing the measurement of accessories.

## 4.4 General Comments

### 4.4-1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

**Barth**

- Overall, the report is well written and organized. The order of the literature review cited in this review charge is slightly different than how it is presented in the actual report, but that is only a minor issue.
- One key thing that would be helpful in the introduction is some better scoping sentences. Fuel economy is affected by a number of different things, generally categorized into four areas: 1) vehicle technology effects; 2) vehicle fuel effects; 3) driver behavior effects; and 4) roadway infrastructure effects. Obviously this report deals with the area of 1), i.e., what kind of on-board vehicle technology exists that can improve fuel economy. Even though it is out of the scope of the report, different fuels and fuel additives have an effect on fuel economy, there is significant research and products in this area. Regarding 3), there is now technology that affects how a driver operates the vehicle. Example of this technology include eco-driving aids and real-time navigational aids showing roadway status (e.g., upcoming grade, traffic, etc.). In a sense, this driver feedback technology changes the "driving cycle" that is applied to the vehicle in a typical testing environment. When employed, this eco-driving feedback technology allows for different levels of fuel economy savings, see DOE vehicle technology program references (e.g., see http://energy.gov/sites/prod/files/2014/07/f17/vss087_verma_2014_o.pdf and http://energy.gov/sites/prod/files/2014/12/f19/2014_amr.pdf). Again, this should at least be mentioned in the introduction or literature review, but should probably not be included in the current analysis. Regarding 4), there are roadway infrastructure and traffic operation techniques that can also affect vehicle fuel economy. These include things like traffic signal synchronization, variable speed limit techniques on freeways, adaptive ramp metering, etc. Although this is not vehicle technology per se, this roadway technology can improve overall traffic fuel economy. Again, this is outside the scope of this report, but perhaps it should still be mentioned in the introduction.
- The NOx reducing technology "LNT" needs to be defined in the report. It is referenced but never explained.

- The report seems to end rather abruptly. Is there or should there be a conclusions section?

**de Ojeda**

Organization: The organization follows a logic structure, providing a review of regulations, review of engine and vehicle technologies, and a detailed performance analysis of technologies beyond 2018 model year products. The review closes with an evaluation of testing an simulation approaches, and recommendations for tractor-trailer and vocational vehicles.

Readability and clarity: The report reads well. The more technical discussions are added in the appendices, which are well documented.

The report needs a Conclusion Section (different than the Executive Summary).

Suggestions regarding formatting:

- Generally, figures may be formatted to match the text font size (and style optionally). The legends, titles, and numbers appear too large. Other figures which appear from other sources, have very small font axis titles (e.g., Figure 4.1).
- Figure and Table titles are capitalized and bolded. The sheer size of these titles "hide" the report section titles. Consider reducing the font size of the figure titles or not capitalizing nor bolding.

A detailed list of suggestion were provided under the "Performance Analysis of Technologies". Here we collect suggestions for the "Executive Summary":

- HD pickup truck table shows 10,000lb GVWR. An asterisk may be inserted to indicate that it was examined at 25,000lb when pulling a trailer (page v).
- The 6.7L Diesel referred in paragraph 3 appears to be the high HP application – please clarify as there are two rating for this engine (page vi).
- Mention of a 4 cylinder version of the Diesel is made, but this is the first time. May clarify that this is a 'modeled' based on the ISB (page viii).
- Subsequent paragraphs beginning with "Section 4.x" could provide more of a summary. Sentences like *"some technologies perform best on drive cycles that emphasize low speed, light load engine operation, while others prefer high speeds and loads"* (Section 4.6) should be avoided. A more explicit address of what technologies apply would be best.

**Lowell**

- It would be very helpful to the reader to include a table in the executive summary which summarizes the findings which are described in the text (range of % fuel reduction for each technology/approach modeled).
- Otherwise I believe that the report is well organized, clear, and readable. I do not believe any major changes are required.

**Midlam-Moher**

With the exception of the section 4, I feel that the document is fairly well organized and readable. I made comments previously regarding section 4 with some specific recommendations.

**Nelson**

Information content of the report is very dense. Detailed descriptions of performance results and the trade-offs associated with multiple technologies are often combined into the same paragraph, making it at times challenging to extract the most important points amid many comparative statements. While not obligatory, some suggestions that might help the reader include:

- Occasionally breaking up some of the longer paragraphs, focusing on only one or two technologies in a single paragraph.
- Using bullet lists within paragraphs to visually separate key points and conclusions.
- State clearly when data is from simulations, lab testing, or track testing.
- Global regulations could be summarized in a table, at least in Section 2.
- The history of the RFPs in the Introduction is confusing, but may be required. It can also be difficult to understand which "SRx" Tasks are in scope and which are not; emphasis should be on what SwRI is being asked to do for the report at hand.

**Nuszkowski**

Overall, the report was organized, readable, and clear with only minor corrections needed (see 4-4).

A table in the executive summary to summarize the results would be very beneficial to the report.

### 4.4-2 Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?

**Barth**

Overall the information provided in the report is sufficiently detailed; various comments on specifics have been provided above.

**de Ojeda**

Generally, the report does a very good job in providing the necessary detail to adequately understand the impact of the technologies in the fuel efficiency improvement roadmap. The text is well coordinated with the appendices – which are very well organized, describing both engines and vehicle modeling efforts.

The report could be enhanced by providing additional detail in

- Fuel penalties associated with the aftertreatment;
- The actual technologies and hardware used to Appendix C to account for the Cd and Crr improvements (page C-13,14);
- How are the weight reductions accomplished, what components contribute to the weight reduction, what materials are being introduced (page C-15)?
- Incorporate and document in the report the effect of weight in the estimation of fuel efficiency.

**Lowell**

- The report and appendixes are very detailed and they thoroughly document the methodology and results of the study.
- To aid the reader in fully understanding the context and implications of this study I recommend that additional information be added in the following areas:

  1. Executive Summary: Add table summarizing the results discussed in the text (see response 4.4-1)
  2. Section 2.1: Provide additional information about the CalHEAT vehicle segmentation approach chosen to organize this study, including: descriptions of the types of vehicles included in each of the six vehicle segments, and estimates of the percentage of in-use vehicles, annual vehicle miles, and annual fuel use and GHGs accounted for by each segment (see response 4.1-1)
  3. Section 2.2.2: Add discussion of fuel economy regulations in the European Union, Mexico, and Brazil and add a summary table comparing approaches in each region (see response 4.1-1)
  4. Section 3.2: Include a more complete discussion of how the vehicles and drive cycles chosen for this study map to the CalHEAT vehicle segments used as an organizing principle for this project. Specifically map the modeled vehicle(s) and drive cycle(s) to the vehicle segments that they represent. Discuss any significant sub-sets of each segment not covered by the study. Specifically address vehicles with significant PTO use to power vehicle-based equipment and how they do or do not fit into this study (see responses 4.1-2 and 4.2-2)
  5. Section 3.2: Include figures showing the speed/time trace for each drive cycle used in the analysis, either in the body of the report or in an appendix (see response 4.2-2)

**Midlam-Moher**

I have no further comment then those made earlier. The most critical point would be to add as much validation and justification of assumptions as possible to the baseline engine models as these drive the accuracy of the technology assessment. I was also suggest that wherever possible the results from the analysis be compared against experimental data in as clear as manner as possible. This lends great confidence in the modeling approach to extrapolate beyond the baseline model.

**Nelson**

More detailed back-up information to reinforce the appropriateness of the coastdown coefficients, and demonstration of vehicle simulations against experimental track data should be provided, as described in the responses to question 4.2-3.

**Nuszkowski**

The vehicle selection needs to not only be discussed in the executive summary. The longest discussion on vehicle selection was in the executive summary.

### 4.4-3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

**Barth**

The strongest part of the report was section 4, in terms of the analysis and comparison of the technologies, and the methodology comparison. The weakest part of the report was the lack of specific figures in the detailed analysis section. The weakest parts of the report can be improved by addressing some of the comments made above, and including some of the figures suggested in the text above.

**de Ojeda**

Strengths:

- Excellent simulation study throughout a very comprehensive list of engine and vehicle technologies. The expertise behind the report is manifested as the authors show the impacts of various technologies on efficiency and emissions, and implications on vehicle installation;
- Very consistent analysis across the engines and vehicles;
- Very informative, brief background descriptions at the technologies presented;
- Methodology used is thorough as illustrated in the systematic approach of adding technology content on the baseline engine and vehicle and reporting the impact on fuel economy;
- The models are run for existing technologies which could be implemented with specified improvements (e.g., improvement on turbocharger efficiency, improvement on drag coefficient).

  The models are also run with new technologies previously not present on that platform and are accompanied by very informative discussions (e.g., the application of GDI on a PFI style engine, lean GDI, VVA, etc.);
- Engines and engine technologies were modeled very well with GTPower. Baseline models were calibrated with experimental engine data, including heat release data from engine testing;
- Engine maps were fed into SwRI Vehicle Simulator tool. This tool handles a wide range of vehicle technologies including automatic transmissions and automated manual transmissions.

Weaknesses:

- The engine simulations are generally more detailed than the vehicle side. For example, no detail (what features) is given regarding the percent reduction in aero drag or rolling resistance;
- The report present savings with respect to miles per gallon. Yet the regulations are prescribed in terms of gallons per ton-millage. The presentation of results with respect to ton-millage would seem more appropriate and useful;
- There is little consideration to weight and packaging of components, with special mention to implications in freight efficiency;
- There is no cost-benefit analysis such as “pay-back” period;

- There is no quantitative analysis of aftertreatment heat management and the fuel penalties associated (DPF, SCR units have very strict requirements to maintain exhaust temperatures), start-up and light off and technologies, impact on certification. All these play significant roles in product development.

**Lowell**

- The strongest part of this report is section 3, the discussion of the results of the engine and vehicle technology modeling. I also believe that section 3.4, the discussion of NOx/fuel economy trade-off, is very well presented and important. Section 4.6, discussion of effects of drive cycle on fuel economy benefit from different technologies, is also very well presented.

- The weakest part of this report is the description of how the vehicles and drive cycles that were modeled were chosen, and specifically the linkage to real-world vehicle segmentation, to provide appropriate context for the reader to understand the relevance and implications of the work. See response 4.4-2 for specific suggestions for improvement.

**Midlam-Moher**

From having done similar simulation work, I feel that this represents a very serious investment of engineering effort and, despite some requests for clarification, believe the work is quite sound technically.

The weakest part is really the converse of this, in that the modeling approach is quite complicated and based on many assumptions. Without literally sifting through the model and validation data, it is difficult to conclude that each and every simulation case is without fault. The best way to address this is to provide as much validation points as possible, whenever possible. If a paper exists that suggests a 6% improvement in FE and the simulation shows 5-9% - that is a good indication that the approach is valid and this should cited. This is done in many cases but not in others.

**Nelson**

Given its potential impact on the definition of future technology packages and drive cycle combinations, Section 4.6 is the strongest part of the report. Any further conclusions that can be derived from data presented in this section would be of interest. For example, are the effects of payload understood well enough across all vehicles and all drive cycles that only one load condition needs to be considered for rulemaking? Are there recommendations of technologies that should move forward and others which should be abandoned?

The weakest part of the reporting is vehicle model validation, which is covered in Appendix C. There is not a sufficiently strong sense of how well the models predict actual fuel consumption of the baseline vehicles. Validation of the slopes for the graphs of changes in fuel consumption as a function of changes in tire rolling resistance (and Cd) can particularly strengthen the report.

Lack of a broader dataset of market segmentation is an acknowledged weakness. This could be addressed in part by other data sources, such as surveys by industry organizations.

**Nuszkowski**

The wide breadth of vehicle and engine technologies analyzed on many different drive cycles was the strongest part of the report.

The weakest parts of the report were the minimum number of engine combustion technologies that were analyzed; minimal discussion on the influence of transient operation on these devices (especially the

turbochargers) and model; and how worksite vocational trucks were represented. Include a lengthier discussion/analysis on engine combustion technologies. In addition, discuss each engine and vehicle technology's influence when operated on a transient cycle.

### 4.4-4 Please provide any other comments you may have on this report.

**Barth**

Overall, good report and appendices.

**de Ojeda**

The report could have added more innovative technologies that may be seen in production:

- Some level oh hybrid, e.g., the mild-hybrid concept program evaluated by John Deere and International under the DOE program (Electric Turbo Compounding… A Technology Who's Time Has Come, EERE, 2006 DEER Session) ; hydraulic hybrid (ref. Hydraulic Hybrid Vehicle Technologies , Clean Technologies Forum, Sacramento, CA, September 9, 2008)

- The report should have dealt with CNG. CNG fuel is taking up a larger role in the MD sector and should be considered. The authors could provide a section comparing the merits and challenges that CNG brings.

- The report should have considered alternative fuels. This is a bit of a disappointment in many ways: the more strict GHG, fuel economy, and emission legislations have made our engines more complex, bulkier, more costly, and more expensive in maintenance. OEMs for the most part have limited their effort on the hardware side while not considering the benefits that better fuel formulations could bring. With a little more foresight, the fuel properties and future fuel resources based on bio-derived sources could be aligned with future legislation at this point in time. The efforts of Volvo, Isuzu and others on the use of Dimethyl Ether is an a good example of the potential simplification that this oxygenated fuel can bring to transportation industry. Ref. ORNL/TM-2014/59 Emissions and Performance Benchmarking of a Prototype Dimethyl Ether-Fueled Heavy-Duty Truck, February 2014.

- No mention of "Dual Fuel Technologies" is made here though it has been shown to both contribute to significant simplifications of aftertreatment and improving the combustion cycle efficiency. Refer to http://www1.eere.energy.gov/cleancities/pdfs/cap_dual_fuel_tech.pdf.

**Lowell**

- In section 3 there are a number of comparisons between the modeled fuel economy and fuel use of the same vehicle with both gasoline and diesel engines. The text points out that the efficiency differences between diesel and gasoline engines are not as large as implied by the stated differences in MPG, due to higher energy content of diesel relative to gasoline. However, the text does not mention the differences in projected CO2 emissions for the gasoline and diesel options. Given that this study is in support of joint EPA/NHTSA regulations of both fuel use and GHGs, I think that it would be instructive and helpful to the reader to include discussion of the relative GHG emissions (g/mile) from the gasoline and diesel engine options modeled.

- On page 78 there appears to be a mistake in the text. The text says "Figure 3.26 below shows the fuel economy performance of the **F-650 truck** with the three engines in their baseline form, all evaluated at 50% payload" while the label on Figure 3.26 indicates that it shows fuel economy performance for the RAM pickup.

**Midlam-Moher**

No other comments.

**Nelson**

A 30% decrease in tire Crr from today's (2014-2015) SmartWay thresholds based on ISO 28580 would result in the following values: Steer 4.55 kg/T; Drive 4.62 kg/T; and Trailer 3.57 kg/T. The assumed improvement target, Crr=3.93 kg/T, given in Appendix C for the T-700, is not consistent with these levels. Use of large changes from baseline can be beneficial to identify trends in simulations. Setting a potentially extreme level of rolling resistance reduction as a target may risk compromises of other performances for future tire development.

**Nuszkowski**

The factors that are to be considered for the report (page iii) included vehicle safety. I did not see any significant discussion on vehicle safety.

Some minor comments and corrections:

Throughout the document:

- replace the term "RPM" with "engine speed"
- Significant figures on benefits (percentages) need to be consistent.
- Combine one sentence paragraphs with other paragraphs
- Repeated text. Especially in the appendix. Can you just reference the earlier descriptions from other vehicles?
- Replace "&" with "and"
- Change "max" to "maximum" and 'min" to "minimum"

Page iv to page v tables: The tables shown are arranged from largest engine size to smallest. The next table is smallest vehicle to largest. Please keep them in the same order.

Page 4 last paragraph: Fuel efficiency definition should be say "… inversely proportional to fuel economy" not "fuel consumption"

Page 9 end of first paragraph: "… 20205 timeframe" Is this number correct?

Page 13 links: Move the links to reference section

Page 16 last paragraph: "taday's" should be "today's"

Pages 19-24: weird spacing on references

Page 27 #4: change "avery" to "a very"

Page 27 #7: Mentioning of Daimler patent. Aren't most technologies covered by a patent?

Page 30: A little too much pushy on HEDGE in this section.

Page 35 second paragraph from bottom: "the actual" is repeated

Table 3.13 and other similar tables: Remove the "%" symbol to make the numbers more readable

Page 40 second paragraph from the bottom: I think the references to Table 3.11 and Figure 3.1 are incorrect.

Page 41 second paragraph: change "…. 0.7% 1.5%" to include a dash

Page 46: The 10-spd manual results seem very high. Was there excessive shifting in the model?

Page 73 Table 3.21 versus Table 3.24: "V-6 to Base ISB" becomes "Base ISB vs. 3.5 V-6" The order is switched yet, the percentages are still the same"

Page 83 Figure 3.30: label of "EGR" is this "Stoich EGR"? Please be consistent with figure labeling.

Page 111 top of the page: "FPT" should be "FTP"

Page 111 last paragraph: "…..about right" change to "…approximately correct"

Page 111 figure label: "RamTechnologies" to "Ram Technologies"

Page A-1: Remove additional space on "1.5. Explore GDI …"

Page A-3: Figure labels needed

Page A-4 figure A 6: Why does the equivalence ratio map extend beyond the fuel map? Are you extrapolating data?

Page A-5 last paragraph: Remove additional paragraph space

Page A-9: Correct the labeling on the figure

Page A-14 very top: Only time an EGR mixer is mentioned. Did the other engines not need one?

Page A-25: Why is the EGR valve before the throttle here?

Page B-7: This is more validation figures than what was shown for the gasoline engines. Why?

Page B-13: The injection parameters would change between using an EGR and not using an EGR.

Page B-26 last paragraph: put spaces in "dowensizeenjoys"

Page B-28: bolding text in figure label

Page B-30: change "BEMP to "BMEP"

Page B-37: Was it mentioned in the text (and not in the appendix) that this engine model was created from a 2007 ISB engine?

Page B-51: Mention the specific "sanity checks" used instead of the term "sanity checks"?

Page C-14 last paragraph: change "… is huge" to "…is significant"

Page C-15 to C-16: table flows over onto next page

Page C-26: Figure C.9 label is on the next page

## 4.5 Overall Recommendation

### 4.5-1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

**Barth**

Based on my review, the report and appendices are acceptable with minor revisions. There are a variety of comments and suggestions made in the above text that the authors could address.

**de Ojeda**

I find the report acceptable with minor revisions.

***Please justify your recommendation:***

The report presents an excellent simulation study throughout a very comprehensive list of engine and vehicle technologies. It is very informative as the report includes valuable background descriptions of the technologies.

The process and criteria for evaluation is the percent in fuel efficiency improvement. This is adequate, yet the report may have used a criteria that aligns with the GHG and fuel regulations (e.g., grams of CO2 per ton-mile, Gallons per 1000 ton-miles).

The selection of 5 engine configurations (and three additional "modeled engine versions") appears adequate and well aligned to the selection of four vehicles.

Metrics for units of work are discussed, including ton-mile, passenger-mile, and cubic-volume-mile. A practical example is used to illustrate the payload effect in a long combination vehicle. The report finishes showing the dependency of technologies on both drive cycles and payload. The discussion is particularly insightful to show that some technologies have a large dependency on these two parameters.

Engine efficiency test procedures are covered well by subdividing them in three categories: technologies where the current tests certification procedures do well; technologies where too small of an impact would compete with the uncertainty of the of the certification tests, yet an estimate can be made via accurate bench testing or modeling; and finally, specific technologies that would not appear on an engine-only certification. Examples are used to illustrate these categories.

The report describes the GEM model and its inputs. The report offers particular insight of VSL and AES to real-world application and customer acceptance. Technologies that are not directly captured in the GEM model are listed and explained is how they can be benchmarked on dedicated stands to calculate the fuel savings.

Examination of The SET test points in a portion of data for Long Haul trucks (limited to one manufacturer with downspeeding technology) show that there is a need to reconsider the right weights. FTP cycle too is compared real world data from vocational vehicles (from same manufacturer), reveling differences, though not as pronounced as with the Long-Haul vehicle data.

**Revisions needed:**

1. The literature review, when addressing the current regulations, should include these in a table rather than simply referencing them. The table should include US and other major regulations (EU, Japan, China). It is also recommended that they be accompanied by the industry average numbers and ranges from current model years (2014 – interim).

2. The technologies chosen are in the in the conservative side, rather well established, there being no "surprise" technology. The review could considered other technologies that have had some presence in the MD-HD vehicle market. This should be a "minor" revision, possibly an added section on the review chapter:

   - Natural Gas – the report can provide important benchmarks and balanced guidance regarding NG vehicles with respect to Diesel powered units (benchmark fuel efficiency, cost of fuel, capital investment);

   - Liquid Petroleum Gas power plants, currently being offered in fleets of school buses, have less power than Diesels, are quiet, clean, and provide a good cost of operation – the same benchmark as above would provide much value.

   - Dual Fuel technologies which provides a significant technology to reduce particular matter and reduce or eliminate the DPF when Diesel is used to ignite natural gas, and can reduce fueling costs,

   - Alternative Fuels, specially fuels that have the potential in the long run to be viable substitutes to fossil fuels and provide significant advantages towards cleaner burning and simpler engine platforms (simpler fuel injection systems, aftertreatment systems). One such example being DME.

   - A technology like Dual Fuel, in the sight of this reviewer, would be as competitive or more feasible than the Rankine waste heat recovery".

   - Dealing with these areas would enhance the report. It would contribute to the long term perspective of highlighting technologies that can significantly impact transportation efficiency.

3. Create a table to help understand the engine-vehicle-class designation used in the report. Also clarify if the 8.9L modeled engine is used – if not used it may be best remove the statements on the 8.9L engine from page 25.

| Class | Vehicle | Diesel | Gasoline |
|---|---|---|---|
| 2a | | | |
| 2b | Ram Pick-up | 6.7 385HP | 3.5L V6 |
| 3 | | *4.5L model* | 6.2L V8 |
| 4 | | | |
| 5 | | | |
| 6 | T270 BOX<br>F-650 Tow Truck | 6.7L 300HP | 3.5L V6<br>6.2L V8 |
| 7 | | | |

| | | | |
|---|---|---|---|
| 8 | T700 | DD15<br>*12.3L model* | |

4. The report should include a conclusion section. This should be different from the Executive Summary.

**Lowell**

- I find this report ACCEPTABLE WITH MINOR REVISIONS. See responses 4.4-2 and 4.4-4 for suggested changes. The analysis appears to be thorough and appropriate to the task, and the methodology and results are thoroughly and clearly described. The suggested minor revisions will provide the reader with better context to understand the relevance of the results to the real world fleet.

**Midlam-Moher**

I feel this report is acceptable with minor revisions for: 1) clarity (section 4 mainly); 2) documentation of assumptions; and 3) additional validation as discussed above. I would state that there is nothing in the report that appears inaccurate, however, in a guiding document like this results should be well vetted as possible. Specific suggestions are described in the previous sections of this review.

**Nelson**

I would recommend the report be published with (a) minor revisions to improve readability, and (b) a moderate-level revision to Appendix C, as has been mentioned earlier in this review. Without this additional validation the report is an excellent simulation study, but still a simulation study. With the data, the report is substantially more convincing and provides a solid basis for both rulemaking and future studies of MD/HD fuel efficiency.

**References:**

1. American Transportation Research Institute, "An Analysis of the Operational Costs of Trucking: 2014 Update", September 2014, available for download at www.atri-online.org.

2. Clayton, W. B. and Bradley, C. R, "Improvement of Vehicle Fuel Economy by Optimizing Effective Tire Rolling Resistance", patent Publication No. WO/2013/119252, August 15, 2013.

3. Clark, S.K., "Rolling Resistance Forces in Pneumatic Tires", U.S. Department of Transportation, Report no. DOT-TSC-76-74, January 1976, available for download at http://ntl.bts.gov/lib/46000/46400/46414/DOT-TSC-76-74.pdf.

4. Delgado, O. and Lutsey, N. "The U.S. SuperTruck Program: Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies", International Council on Clean Transportation (ICCT), Whitepaper, 2014, http://www.theicct.org/sites/default/files/publications/ICCT_SuperTruck-program_20140610.pdf.

5. European Tyre and Rubber Manufacturers' Association, "EU Tyre Labelling Regulation 1222/2009: Industry Guideline on tyre labeling to promote the use of fuel-efficient and safe tyres with low noise levels" Version 3, November 2011, http://www.etrma.org/uploads/Modules/Documentsmanager/2011-11-30--industry-guideline-on-tyre-labelling-(vers3).pdf.

6. Hausberger, S., Rexeis, M., Blassnegger, J., and Silberholz, G., "Evaluation of fuel efficiency improvements in the Heavy-Duty Vehicle (HDV) sector from improved trailer and tire designs by application of a new test procedure", Institute for Internal Combustion Engines and Thermodynamics for the International Council on Clean Transportation, Report no. I-24/2011, December 15, 2011.

7. Miller, J. D. and Facanha, C., "The State of Clean Transport Policy: A 2014 Synthesis of Vehicle and Fuel Policy Developments", International Council on Clean Transportation, 2014, available for download at www.theicct.org/state-of-clean-transport-policy-2014.

8. National Research Council, "Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two, First Report", ISBN 978-0-309-30237-1, 2014.

9. National Research Council, "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles", ISBN 978-0-309-14982-2, 2010.

10. North American Council for Freight Efficiency, "2014 Fleet Fuel Efficiency Benchmark Study", August 21, 2014, http://nacfe.org/wp-content/uploads/2014/09/NACFE-2014-Study-Report-FINAL-083114.pdf.

11. North American Council for Freight Efficiency, "Confidence Report on 6x2 Axles", January 13, 2014, http://nacfe.org/wp-content/uploads/2014/01/Trucking-Efficiency-6x2-Confidence-Report-FINAL-011314.pdf.

12. North American Council for Freight Efficiency, "Confidence Report on Idle-Reduction Solutions", June 25, 2014, http://carbonwarroom.com/sites/default/files/reports/Idle-Reduction_Confidence_Report.pdf.

13. North American Council for Freight Efficiency, "Confidence Report: Electronically Controlled Transmissions", December 14, 2014, http://nacfe.org/wp-content/uploads/2014/12/Trucking_Efficiency_Transmissions_Confidence_Report.pdf.

14. North American Council for Freight Efficiency, "Tire Pressure Systems", August 15, 2013, http://nacfe.org/wp-content/uploads/2014/01/TPS-Detailed-Confidence-Report1.pdf.

15. SAE International, "Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques", SAE J1263, March 2010.

16. U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA), "Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles", Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.

**Nuszkowski**

(2) Acceptable with minor revisions. Please see Section 4 [4.4-1; 4.4-2; 4.4-3; 4.4-4] above for my revisions.

# APPENDIX A

# REVIEWER CURRICULUM VITAE

**MATTHEW J. BARTH**
Jacques and Eugene Yeager Families Endowed Chair; Professor of Electrical Engineering
Director, Center for Environmental Research and Technology
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**Education**

| | |
|---|---|
| 1990 - 1991 | Post-Doctoral Research Scholar, Systems Engineering; Osaka University, Japan |
| 1986 - 1990 | Ph.D. (1990), Electrical and Computer Engineering; University of California, Santa Barbara |
| 1986 - 1987 | Visiting Research Scholar, Information Engineering; University of Tokyo, Japan |
| 1985 - 1986 | M.S. (1986), Electrical and Computer Engineering; University of California, Santa Barbara |
| 1980 - 1984 | B.S. (1984), Electrical Engineering / Computer Science; University of Colorado, Boulder |
| 1982 - 1983 | Study Abroad Student, Electrical Engineering; University of Stuttgart, West Germany |

**Employment**

1992 - present ***University of California-Riverside:***

***Electrical Engineering*:** Professor 2003-present; Associate Professor 1998-2003; Adjunct Assistant Professor 1992-1998. Part of Intelligent Systems Group. Cooperative faculty appointments: Mechanical Engineering, Chemical/Environmental Engineering.

***UCR Center for Environmental Research and Technology (CE-CERT)*:** Director 2007-present; Interim Director 2004-2007; Associate Director 1998-2003; Research Faculty 1992-1998. Research focus: intelligent transportation systems for the environment, transportation/emissions simulation modeling, sustainable energy systems, electric-drive vehicles, intelligent sensing/control.

1990 - 1991 ***Department of Systems Engineering, Faculty of Engineering Science, Osaka University, Japan*:** Visiting Research Postdoctoral Fellow. Investigated transportation technology, mobile agent navigation, computer vision, and control.

1985 - 1990 ***Center for Robotic Systems in Microelectronics, University of California, Santa Barbara***: Graduate Research Assistant. Member of the robot perception group. Emphasis on attentive vision techniques, multi-level feedback sensory/control mechanisms, machine color vision, and embedded systems.

1985 - 1986 ***General Research Corporation, Santa Barbara, California***: Member of the Technical Staff, Advanced Technology Division. Developed data acquisition systems and electronics associated with electro-optical electromagnetic photonic field sensors.

1979 - 1984 ***Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder***: Command controller of university research satellite, data logging and formatting.

**Research Interests**

Transportation/emissions modeling, intelligent transportation systems, vehicle activity analysis, sustainable energy systems, electric vehicle technology, intelligent sensing /control, multi-agent systems.

**Professional Service**

***Memberships:***

- Institute of Electrical and Electronic Engineering (IEEE): Member-1990, Senior Member-2000, Fellow-2014, Intelligent Transportation System Society, Vehicular Technology Society
- Institute of Electrical and Electronic Engineering (IEEE): Intelligent Transportation System Society President 2014-2015; President Elect 2013; Vice President-Conferences 2011-2012;
- Transportation Research Board: Member, Transportation and Air Quality Committee; Intelligent Transportation Systems Committee, New Transportation Technology Committee
- U.S. EPA Mobile Sources Technical Review Subcommittee: Co-Chair, Modeling Workgroup
- ITS America: Sustainable Transportation Committee
- Southern California Association of Governments: Committee Member, University Advisory Group

**Awards and Honors**

- Yeager Families Endowed Chair in Engineering at UC Riverside, 2007 – present
- IEEE Fellow, for pioneering research in Intelligent Transportation Systems, 2014
- City of Riverside, Smart Riverside Innovation Honoree, 2013
- Federal Highway Administration Connected Vehicle Technology Challenge Award, 2011.
- Innovative Transportation Systems Clean Air Award, Air Quality Management District (with Honda), 2010
- Member of the Governor's Expert Review Panel on Transportation Research and Technology, 2008
- Transportation Research Board Pyke Johnson Award , 2006
- Invited Speaker, National Academy of Engineering's 2006 Annual Symposium on Frontiers of Engineering
- Discover Magazine Awards for Technological Innovation, National Finalist 2001
- Tau Beta Pi: Outstanding Teaching Assistant in Electrical and Computer Engineering, 1988
- NASA: Public Service Group Achievement Award for the control and operations of university satellite, 1984

**SUMMARY OF PROFESSIONAL ACCOMPLISHMENTS**

**Dissemination of Research**

- Journal Papers: 66; Refereed Conference Papers: 190; Books and Book Chapters: 11; Technical Reports: 141
- U.S. Patents: 8; International Patents: 6
- Presentations, Invited Talks, Keynote Speech (2010-2013): 44

**Advising & Mentoring**

- Postdoctoral Scholars Directly Supervised: 8
- Graduate Students graduated as Major Advisor: 8 Ph.D. (7 in progress), 22 M.S. (2 in progress).
- Undergraduate Student Researchers Directly Advised: 38

**Recent Research Grants**

- Total Number of New Grants as Principal Investigator (2010 - 2013): 18 for $6.1M
- Additional Number of Grants as Co-Investigator (2010 - 2013): 4 for $1.2M

# William de Ojeda, PhD, PE

## EDUCATION

| | |
|---|---|
| **Illinois Institute of Technology** | Ph.D. Mechanical and Aerospace Engineering, '96 |
| **University of Virginia** | M.Sc. Mechanical and Aerospace Engineering, '92 |
| **The Cooper Union** | B.S. Mechanical Engineering, '90<br>Awarded **Stefano Excellence Award** for Capstone Design |

## INDUSTRIAL EXPERIENCE

### WM International Engineering, Darien — 2014

Director of Engineering

Responsible for development of fuel injection and charge air systems for advanced Diesel, Gasoline, Natural Gas, Dual Fuel and alternative fuel Powertrains. Work includes design, prototyping, controls and benchmarking.

### Navistar, Lisle — 1997-2014

Technical lead on the SCR engine deployment (2013-14)

Lead system integration and execution of air and fuel strategies and OBDII features on new HD product.

**Manager, Advanced Combustion and Controls (2005-2012)**

Principal Investigator on **DOE Supertruck** program (2010-2012)

Responsible for integration of new technologies onto engine and vehicle platform including Variable Valve Actuation, new High-Pressure Common Rail, Turbo-compounding and Organic Rankine Cycle, base engine improvements, aftertreatment systems such as DPF, SCR and LNT Supervised staff across multi-disciplinary specialties, multiple engine dynamometer cells, and subcontractors including ANL, Federal Mogul, and BOSCH. Program sponsored by DOE grant **DE-EE0003303** High Efficiency Engine and Vehicles.

Principal Investigator on **Low Temp Comb Demonstrator** (2005-2010)

Directed redesign of 6.4L engine to meet 2010 emissions based on low temperature combustion. Scope and major milestones of program included design of injectors, combustion chamber, turbocharger and EGR system, and a new electro-hydraulic variable valve actuation system. Developed prototype ECU to run all engine functions including combustion feedback. Reposabilities included the assembly of a team of engineers in the areas of controls, fuel injection, CAD, combustion, and elecro-hydraulics. Supervised subcontractors including LLNL, UC Berkeley, Borg Warner, Siemens, and Ricardo. Program sponsored by DOE grant **DE-FC26-05NT42413** High Engine Efficiency and Clean Combustion Program.

Sr. Product Engineer, Advanced Technologies (2001-2005)

Responsible for dSPACE/Matlab Simulink software and integration into the early Siemen's EDU prototypes. Models focused in air-fuel management strategies on 2007MY V8 engine product and the transition to MAF and TQ control structures. Specific contributions included: coordinated EGR-VNT-BYPASS actuation (patented algorithms and modeling for coordinated control during transients of EGR and two-stage turbocharger units with bypass); fast EGR estimator (developed accurate EGR estimation based on oxygen sensors); developed injection timing compensator for enhanced combustion control over transients.

Engineer, Advanced Technologies (1997-2001)

Responsible for Variable Displacement (inlet throttle) fuel injection pump development: Contributed to design of flow and pressure control valve with simulation and testing on bench and on engine. Worked with valve (INVENSYS) and pump (SHEPPARD) manufacturers to deliver product to the I6 and V8 engine lines.

Design of a direct throttle control to optimize flow losses incurred in the pressure regulator. Implemented design in pump and demonstrated performance improvements in bench. Special control system was developed to apply this to fast transients to match performance response to the fast acting pressure regulator.

Lead design for Variable Valve actuation Program - Navistar's Camless engine. Responsible for extensive design, benchmarking, electronic interface, prototype procurement and engine implementation.

### APTEK-Air Force Contract Work, Colorado Springs — 1996

Design engineer for Air Force flight control project

Designed wind tunnel imaging and contros to capture turbulent effects on lift-reduction on aircraft.

## AWARDS

**Stefano Excellence Capstone Design Award** for "A Microcomputer-Interfaced Steam Turbine Test Stand", 1990.
**Distinguished Paper-Presentation** "Effect of Variable Valve Timing on Combustion Characteristics", SAE 2010.

## TEACHING

Lecturer of Graduate Level **Fundamentals of Combustion** at the Illinois Institute of Technology.
SAE instructor C1332 "**Variable Valve Actuation: Design and Performance Impact on Advanced Powertrains**"
Instructor Speaker at the University of Toronto NSERC CREATE **Clean Combustion Engines Summer School**.

## PROFESSIONAL AFFILIATIONS AND REGISTRATION

Member of the SAE, ASME
Licensed Professional Engineer from the Sate of Illinois no. 062-053677
Designing On-Board Diagnostics for Light and MD Emissions Control Systems, SAE Course Mastered, 2014

## PATENTS

| | |
|---|---|
| US2014/0053811 | **System and method of controlling combustion in an engine having an in-cylinder pressure sensor**, W de Ojeda, Raul Espinosa, 27 Feb 2014. |
| US2013/0218439 | **Controlling Variable Valve Actuation System**, Raj Kumar, W de Ojeda, James Popp, Daniel Cornelius, 22 Aug 2013 |
| US2013/0213352 | **Start of Injection timing**, Raj Kumar, W de Ojeda, I Sagalovich, 22 Aug 2013 |
| US2012/022857 | **Multi-fuel engine with variable valve timing**, W de Ojeda, I Sagalovich, 27 Jan 2013 |
| US2011/0079008 | **Strategy for Control of Recirculated Exhaust Gas to Null Turbocharger Boost Error**, 7 April 2011, W de Ojeda, J Popp |
| US no. 8,069,828 | **Intake Valve Closing Hydraulic Adjuster**, 6 Dec 2011, W de Ojeda, Daniel Cornelius |
| US no. 7,184,877 | **Model-Based Controller for Auto-Ignition Optimization in a Diesel Engine**, 27 Feb 2007, W de Ojeda |
| US no. 7,168,396 | **Variable Compression Ratio Strategy for Improving Combustion Processes in Alternative Combustion Compression Ignition engines**, 30 Jan 2007, T. R. Bulicz, X. Gui, W de Ojeda |
| US no. 7,013,212 | **Air Management Strategy for Autoignition in a CI Engine**, 14 March 2006, W de Ojeda, X Yang |
| US no. 7,004,123 | **Unit Trigger Actuator**, W de Ojeda, 28 February 2006 |
| US no. 6,786,186 | **Unit Trigger Actuator**, W de Ojeda, 7 September 2004 |
| US no. 6,763,790 | **Poppet Valve Actuator**, J.P. Watson and W de Ojeda, 20 July 2004 |
| US no. 6,681,743 | **Pressure Control Valve with Flow Recovery**, W de Ojeda, 27 Jan. 2004 |
| US no. 6,338,320 | **Hydraulically-assisted engine valve actuator**, W de Ojeda, 15 Jan. 2002 |
| US no. 6,263,842 | **Hydraulically-assisted engine valve actuator**, W de Ojeda, P. Das, 24 July 2001 |
| US no. 6,044,815 | **Hydraulically-assisted engine valve actuator**, W de Ojeda, 4 April 2000 |

## Selected Publications

1. "Impact of Fuel Cetane Number on Combustion of a Gasoline-Diesel Dual-Fuel Heavy-Duty Multi-Cylinder Engine", Andrew Ickes, Thomas Wallner, Yu Zhang, **William de Ojeda**, 2014-0101309, SAE 2014 World Congress and Exhibition.

2. "Development of Dual-Fuel Low Temperature Combustion Strategy in a Multi-Cylinder Heavy-Duty Compression Ignition Engine Using Conventional and Alternative Fuels", Yu Zhang, Ilya Sagalovich, **William De Ojeda**, Andrew Ickes, Thomas Wallner, David D. Wickman, 2013-01-2422, SAE 2013 Commercial Vehicle Engineering Congress, Chicago.

3. "Ignition Control of Gasoline-Diesel Dual Fuel Combustion", Xiaoye Han, Kelvin Xie, Ming Zheng, **William de Ojeda**, 2012-01-1972, SAE 2012 Commercial Vehicle Engineering Congress, Chicago.

4. "Engine Technologies for Clean and High Efficiency Heavy Duty Engines", **William de Ojeda**, Raj Kumar, 2012-01-1976, SAE 2012 Commercial Vehicle Engineering Congress, Chicago.

5. "Computational Study of Combustion Optimization in a Heavy-Duty Diesel Engine Using In-Cylinder Blending of Gasoline and Diesel Fuels", Yu Zhang, **William de Ojeda**, David Wickman, 2012-01-1977, SAE 2012 Commercial Vehicle Engineering Congress, Chicago.

6. "A High Efficiency, Dilute Gasoline Engine for the Heavy-Duty Market", Shinhyuk Michael Joo, Terrence Alger, Christopher Chadwell, **William de Ojeda**, Jacob Zuehl, Raphael Gukelberger, 2012-01-1979, SAE 2012 Commercial Vehicle Engineering Congress, Chicago.

7. "Exhaust Hydrocarbon Speciation from a Single-Cylinder Compression Ignition Engine Operating with In-Cylinder Blending of Gasoline and Diesel Fuels", **William De Ojeda**, Yu Zhang, Kelvin Xie, Xiaoye Han, Meiping Wang, Ming Zheng, 2012-01-0683, SAE 2012 World Congress and Exhibition.

8. "The Impact of Fuel Properties on Diesel Low Temperature Combustion", **William de Ojeda**, Tytus Bulicz, Xiaoye Han, Kelvin Xie, and Ming Zheng , Fred Cornforth, 2011-01-0329, SAE 2011 World Congress and Exhibition.

9. "The Impact of Fuel Properties on Diesel Low Temperature Combustion", **William de Ojeda**, Tytus Bulicz, Xiaoye Han, Kelvin Xie, and Ming Zheng , Fred Cornforth, 2011-01-0329, SAE 2011 World Congress and Exhibition.

10. "Effect of Variable Valve Timing on Low-Load Diesel Combustion Characteristics", **William de Ojeda**, Dan Cornelius, 2010-01-1124, SAE 2010 World Congress and Exhibition.

11. "Development of a Fuel Injection Strategy for Partially Premixed Compression Ignition Combustion", **William de Ojeda**, Philip Zoldak, Raul Espinosa, Raj Kumar, 2009-01-1527, SAE 2009 World Congress and Exhibition.

12. "Development of a Fuel Injection Strategy for Diesel LTC", **William de Ojeda**, Phil Zoldak, Raul Espinosa, Raj Kumar, 2008-01-0057, SAE 2008 World Congress and Exhibition

13. "Design of a Model Based Controller for Regulation of Autoignition", **William de Ojeda**, IMECE2005-80594, ASME 2005 Congress, November 5-11, Orlando, FL.

14. "An Electronic Controlled Throttle for Torque and Stability Optimization in a Fuel Injection Pump", **William de Ojeda** and Christer Fjellgren, FEDSM2005-77003, ASME Fluids Congress, June 19-23, Houston, TX.

15. "Stability of a Pressure Compensated Circuit for an Inlet Throttled Pump", **William de Ojeda** and Arturo Hernández, FEDSM2005-77086, ASME Fluids Congress, June 19-23, Houston, TX.

16. "The Needle Valve Actuator", **William de Ojeda** and Jorge Fernández, IMECE 2003-43607 Congress, Washington DC.

17. "A Microcomputer-Interfaced Steam Turbine Test Stand for an Undergraduate Thermo/Fluids Laboratory", Joel Hollenberg and **William de Ojeda**, 1990 ASEE Annual Conference, Toronto, Canada.

## Journal Publications

1. "Impact of Cetane Number on Combustion of a Gasoline-Diesel Dual-Fuel Heavy-Duty Multi-Cylinder Engine," Ickes, A., Wallner, T., Zhang, Y., and **de Ojeda, W.**, *SAE Int. J. Engines* 7(2): 2014.

2. "Development of Dual-Fuel Low Temperature Combustion Strategy in a Multi-Cylinder Heavy-Duty Compression Ignition Engine Using Conventional and Alternative Fuels," Zhang, Y., Sagalovich, I., **de Ojeda, W**., Ickes, A. et al., SAE Int. J. Engines 6(3): 2013

3. "Emission and Ignition Control for a Gasoline Diesel Dual Fuel Engine", Submitted to the Journal of Energy Research, 2013, X Han, K Xie, W de Ojeda, M Zheng

4. "Engine Technologies for Clean and High Efficiency Heavy Duty Engines", **W de Ojeda**, R Kumar, SAE Int .J. Engines 5(4) 1759-1767: 2012

5. "A High Efficiency, Dilute Gasoline Engine for the Heavy-Duty Market", Shinhyuk Michael Joo, Terrence Alger, Christopher Chadwell, William de Ojeda, Jacob Zuehl, Raphael Gukelberger, 2012-01-1979, SAE Int. J. Engines 5 (4) 1768-1789: 2012

6. "The Impact of Fuel Properties on Diesel Low Temperature Combustion", **William de Ojeda**, Tytus Bulicz, Xiaoye Han, Kelvin Xie, and Ming Zheng , Fred Cornforth, 2011-01-0329, SAE Int. J. Engines June 2011 4:188-201

7. "Development of a Fuel Injection Strategy for Partially Premixed Compression Ignition Combustion", **William de Ojeda**, Philip Zoldak, Raul Espinosa, Raj Kumar, SAE Int. J. Engines October 2009 2:1473-1488.

8. "Hydraulic Flow Compensator for Fast Switch Device", William de Ojeda and Francisco Ruiz, ASME Journal of Dynamics, Systems, Measurements and Controls, Vol. 125, pp. 509–514, September 2003

## Conferences and Guest Speaker Events

1. "High-pressure Oil Intensified DME Fuel Injection System Development for Engine-Conditions Spray Combustion", **6th International DME Conference,** San Diego, 7-9 October 2014

2. "Critical Research Needs Relevant to Field of Heavy-Duty Engine Combustion", **Advanced Engine Concepts MOU meeting at the SANDIA CRF**, February 2-7, 2013

3. "Development and Demonstration of a Fuel-Efficient HD Engine (Dept of Energy Supertruck Program)", **DOE DEER CONFERENCE**, October 16, 2012, Dearborn, Michigan.

4. "DOE Supertruck Program: High Efficiency Engine Technologies with Emphasis on Heat Transfer Systems and Components", **NARSA Heavy Duty Heating and Cooling Conference**, Ann Arbor, MI, Sep 20-22, 2012.

5. "IC Engine System Technologies for High Efficiency Heavy Duty Vehicles" Guest Speaker at **SAE Heavy Duty Vehicle Symposium**, Troy, Michigan, 30 Nov 2011.

6. "Development and Demonstration of a Fuel-Efficient HD Engine (Dept of Energy Supertruck Program)", **DOE DEER CONFERENCE**, October 3, 2011, Detroit, Michigan.

7. "Impact of Variable Valve Timing on Low Temperature Combustion", **DOE DEER CONFERENCE**, September 27-30, 2010, Detroit, Michigan

8. "Low Temperature Combustion Demonstrator for High Efficiency Clean Combustion", **DOE DEER CONFERENCE,** Dearborn, Michigan, August 3-6, 2009

9. "Low Temperature Combustion Demonstrator for High Efficiency Clean Combustion", **DOE DEER CONFERENCE**, 26 Feb 2008

10. "Development of a Multi-Cylinder Diesel Engine for HCCI Operation", **Homogeneous Charge Compression Ignition Symposium**, Sep 24-26 2006, San Ramon, California

11. "Performance of an Inlet Throttle Diesel Fuel Injection Pump", **SICFP Congress**, 2005, June 1-3, Linköping, Sweden.

## Other Background

- Mentor at Midtown Center for high school students (1992-2009) and at Darien Center (2010-present).
- Founder - Commodore of the Illinois Institute of Technology Sailing Club.
- Fluent in speaking and writing Spanish and some skill in German.

# M.J. Bradley & Associates LLC

## Dana M. Lowell

***Senior Vice President & Technical Director***

**Areas of Expertise**

- Advanced vehicle emissions reduction technologies
- Vehicle technology development and deployment
- Transit maintenance management
- Vehicle emissions testing
- Diesel inspection and maintenance programs
- Transit vehicle specification and procurement support
- Life cycle cost modeling and financial analysis
- Project management

Dana has worked in MJB&A's advanced vehicle technology group since 2004, providing strategic analysis, project management, and technical support to mobile source emissions reduction programs. His mobile source project work includes evaluation and implementation of advanced diesel emissions controls, alternative fuels, and advanced hybrid and fuel cell electric drives, as well as development and implementation of diesel emissions testing programs for a range of onroad and nonroad heavy-duty vehicle types. Dana brings to clients a wealth of practical knowledge and experience, the real-world perspective of a major fleet operator, and a proven track record in technology implementation.

Dana has 25 years professional experience in the transportation and government sectors. Prior to joining MJB&A, Dana spent seven years as the Assistant Chief Maintenance Officer for Research & Development at MTA New York City Transit's Department of Buses. In his role with NYC Transit, Dana was responsible for both evaluation and implementation of clean fuel technology programs, including technology and vehicle testing, emissions testing and fleet emissions modeling, component/vehicle specification, maintenance program analysis, applications engineering support, financial analysis, budget development and planning, procurement support, and project management. Under his leadership, NYC Transit developed and executed an aggressive program to implement new technologies fleet-wide, resulting in the creation of NYC Transit's Clean Fuel Bus Program to reduce exhaust emissions from the fleet of 4,500 fixed-route transit buses.

A recognized electric drive and clean fuel expert within transit, Dana has made numerous presentations at industry conferences and workshops sponsored by APTA, TRB, SAE, US EPA, the Canadian Urban Transit Association, the Electric Power Research Institute, the National Parks Service and the World Bank. He has also served on advisory committees for the Harvard Center for Risk Analysis and the US EPA's Environmental Technology Verification Program.

## Representative MJB&A Projects

- NYPA Fleet Analysis – Options to Reduce GHG Emissions
- EDF/Ceres, Effect of EPA Phase 2 Fuel Efficiency Regulations on Freight Rates
- Comparison of Fuel Economy & Emissions from Modern Diesel, CNG, and Hybrid Buses

- Federal Motor Carrier Safety Administration, Recommended Updates to Safety Regulations to Accommodate Electric Drive Vehicles
- Federal Motor Carrier Safety Administration, Training Program for Commercial Vehicle
- Inspectors in Detecting Fuel Leaks from CNG, LNG, and LPG Vehicles
- Port Authority of Allegheny County Bus Fleet Emissions Analysis
- BAE Systems, Hybrid Bus Fuel Economy Testing
- New York City Business Integrity Commission, Analysis of "Age-out" Policy Options to Reduce
- Emissions form Commercial Refuse Trucks in New York City
- Environmental Defense Fund, Policy Options to Reduce Fugitive Emissions from Natural Gas Production Facilities
- ICCT, Policies to Address Electric Vehicle-Grid Integration
- ICCT, Evaluation of Methane Leakage from LNG Marine Fuel Bunkering
- Clean Air Task Force, Diesel Emissions Reduction Policy Toolkits
- Clean Air Task Force, Diesel Black Carbon Climate Comparisons
- New York Power Authority, Hybrid School Bus Demonstration Program
- Federal Motor Carrier Safety Administration, Recommended Updates to Safety Regulations to Accommodate Natural Gas Vehicles
- Regulatory Support to Heavy-duty Diesel Engine Manufacturers for Transition from EPA Tier 2 to EPA Tier 3/4 Regulations
- BAE Systems, Technical Marketing Support and Analysis for Sales of Hybrid-Electric Transit Buses
- Federal Motor Carrier Safety Administration, Guidelines for The Use of Hydrogen Fuel in Commercial Vehicles
- ICCT, Analysis of Trailer Technologies Available to Increase Freight Vehicle Efficiency
- American Clean Skies Foundation, Natural Gas for Marine Vessels, U.S. Market Opportunities
- American Bus Association, Comparison of Coach Bus Service to Amtrak and to the Essential Air Service Program
- ICCT, Policy Options to Address Urban Off-Cycle NOx Emissions from Euro IV/V Trucks
- Chelsea Collaborative, TRU Electrification at New England Produce Center
- Volpe Transportation Center, Fuel Cell Bus Life Cycle Cost Model
- Volpe Transportation Center, Fuel Cell Bus Maintenance Manual & Training Program
- New York Power Authority, Green Fleet Options Analysis
- Clean Air Task Force, Technical Support for Diesel Emission Reduction Policy Development
- Great Lakes Towing, Emissions Testing of SCR-equipped Marine Power Barge
- Conservation Law Foundation, Review of Massachusetts Policies to Reduce GHG from the Transportation Sector
- ICCT, Support for Heavy-Duty Vehicle Fuel Economy/GHG Regulation
- American Lung Association, Technical Support for Energy Policy Development
- CSX, Gen-set Locomotive Emissions Testing
- Keyspan Energy Delivery, Current and Proposed Transportation Technology Review
- Environment Canada, Oil Sands Sector Emission Reduction Feasibility Study
- Translink/GVTA, Bus Technology Demonstration Program, Phase 1, 2, 3 & 4
- Massachusetts Bay Transportation Authority (MBTA), In-service CNG Bus Test Program
- MBTA, Development of an Enhanced Bus Emissions Monitoring and Control Program
- American Bus Association, Transit Modes & GHG Offset Analysis

- Nicholas Institute, BEST BUS Life Cycle Cost and Emissions Model
- PANYNJ, Brooklyn Cruise Terminal Shore Power Feasibility Study
- Massachusetts Department of Environmental Protection, Diesel Engine Retrofits in the Construction Industry: A How to Guide
- STAPPA/ALAPCO, Guidance for the Control of Fine Particulate Matter Emissions from Industry Sectors
- ESP, U.S./Mexican Border Remote Sensing Emissions Testing Project
- Environmental Defense, New York City Idling Emissions Calculator
- NRDC, MTA New York City Transit Bus Fleet Emissions Analysis
- NESCAUM, Region 1 and Region 2 Marine Engine Repower Project
- Northeast Utility Truck Retrofit Program

## Prior Work Experience

| | |
|---|---|
| July 1996 – May 2004 | MTA New York City Transit, Department of Buses<br>*Assistant Chief Maintenance Officer, Research & Development* |
| March 1993 – June 1996 | MTA New York City Transit, Dept. of Capital Programs<br>*Manager of Capital Investment Analysis* |
| Feb 1990 - Feb 1993 | City of New York, Office of Management and Budget<br>*Supervising Project Manager, Value Engineering* |
| Sept 1985 – Sept 1989 | United States Army, 299th Engineer Battalion<br>*Battalion Adjutant; Combat Engineer Platoon Leader* |

## Education

Leonard N. Stern School of Business, New York University, New York, NY

*Masters of Business Administration; co-major in Management and Operations Management, 1995*
*Mayor's Graduate Scholarship; Dean's Award for Academic Excellence*

Princeton University, Princeton, NJ

*Bachelor of Science in Mechanical Engineering, 1985*
*Summa Cum Laude; Phi Beta Kappa; Tau Beta Pi*
*Four-year R.O.T.C. scholarship; Distinguished Military Graduate*

## Professional Activities

- NESCAUM/MassDEP training on short-lived climate forcers, 2010
- Massachusetts Department of Environmental Protection and MASS Highway diesel retrofit training, 2008
- Chair of Hybrid Bus Working Group, Electric Bus Subcommittee; American Public Transit Association, September 1999 – May 2003

- Member, Technical Advisory Panel for Project C-10 - Transit Bus Technology Related Research; Transit Cooperative Research Program
- Member, Technical Council; Transit Standards Consortium, November 2000 – December 2002
- Member, Technical Screening Committee, FY 2000 Research Program; Transportation Research Board
- Organizer and Session Chair, SAE TOPTEC: Hybrid Electric Vehicles in the Bus & Truck Markets; SAE International, New York, NY, May 2000
- Panelist, Alternative Fuels CUTRcast web-panel session; Center for Urban Transportation Research, July 2000; www.nctr.usf.edu/netcast/altfuels.htm
- Member, Technical Review Panel; U.S. Environmental Protection Agency Environmental Technology Verification Program, November 2000
- Member, Advisory Panel on Alternative Propulsion Technologies; Harvard Center for Risk Analysis, October 1999
- Trainer on alternative fuel technologies; National Park Service Training Session on Alternative Transportation Systems, Philadelphia, PA, November 1999
- Member, Peer Review Panel, South Boston Piers Area Transit Way, Massachusetts Bay Transportation Authority, Boston, MA
- Member, Clean Propulsion & Support Technology Committee, American Public
- Transportation Association

## *Conference Presentations*

- International Association of Ports and Harbors Conference, IAPH 2013
- ICCT International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, 2012
- IUAPPA, World Clean Air Congress, 2010
- Transportation Research Board Annual Meeting, 2006
- World Resources Institute/USAID Workshop on Coupling GHG Reductions with Transport & Local Emissions Management, 2005
- World Bank Training Session on Diesel Pollution, 2004
- World Bank Clean Air Initiative – Diesel Days, Washington DC, January 2003
- Philadelphia Diesel Difference Conference, Philadelphia, PA, May 2003
- Diesel Engine Emissions Reduction (DEER) Conference, US Department of Energy, Newport, RI, August 2003
- EPA-NESCAUM Diesel Retrofit Workshop, New York, NY, October 2003
- SAE Truck and Bus Meeting, November, 2003
- Better Air Quality for Asia Workshop (BAQ 2003), World Bank, Manila, Philippines, December 2003 – video presentation
- Transportation Research Board, 2002 Annual meeting, January 2002
- APTA 2002 Bus & ParaTransit Conference, American Public Transit Association, May 2002
- EESI/NESEA Congressional Briefing on Cleaner Transportation Technologies, Washington, DC, May 2002
- APTA 2001 Bus & ParaTransit Conference, American Public Transit Association, May 2001
- CUTA Annual Conference, Canadian Urban Transportation Association, June 2001
- World Bank Clean Air Initiative Workshop for Lima and Callao, Lima, Peru, July 2001

- World Bus and Clean Fuel Expo 2001, August 2001
- North East Sustainable Energy Association (NESEA), Energizing Schools 2001 Conference, October 2001
- SAE Truck and Bus Meeting, November, 2001
- Transportation Research Board, 2000 Annual meeting, January 2000
- APTA 2000 Bus & ParaTransit Conference, American Public Transit Association, May 2000
- Electric Bus Users Group Workshop, Electric Power Research Institute, March 2000
- Diesel Emissions Control Retrofit Workshop, Corning Inc., March 2000
- Board of Directors Alternative Fuels Workshop, Washington Metropolitan Area Transit Authority, July 2000
- SAE Hybrid Electric Vehicles TOPTEC, May 1999
- Bus Technology & Management Conference, American Public Transit Association, May 1998
- NAEVI 98, North American EV & Infrastructure Conference and Exposition, December 1998

## *Publications*

- Lowell, D., Seamonds, D., "Coming Soon To a Fleet Near You: EPA/NHTSA Fuel Efficiency and GHG Standards For Medium- and Heavy-Duty Trucks", Environmental Energy Insights, May 2014
- Lowell, D., "Short-term Climate Impact of Diesel Emission Reduction Projects", Clean Air Task Force, December 2013 "Comparison of Modern CNG, Diesel and Diesel Hybrid-Electric Transit Buses: Efficiency & Environmental Performance", November 2013
- Lowell, D., "Port Authority of Allegheny County Bus Fleet Emissions 2005 – 2019", Pittsburgh Foundation, October 2013
- Lowell, D., Seamonds, D., "New York City Commercial Refuse Truck Age-out Analysis", Environmental Defense Fund and New York City Business Integrity Commission, September 2013
- Wang, H., Lutsey, N., Lowell, D., "Consideration of the Lifecycle Greenhouse Gas Benefit from Liquefied Natural Gas as an Alternative Marine Fuel", submitted to International Maritime Organization, Sub-committee on Bulk Liquids and Gas by Institute of Marine Engineering, Science and Technology (IMarEST), October 2013
- Lowell, D., "NYPA Hybrid Electric School Bus Evaluation Project, Phase 2 FINAL REPORT", New York Power Authority, September 2013
- Whitman, A., Lowell, D., Balon, T., "Electric Vehicle Grid Integration in the U.S., Europe, and China: Challenges and Choices for Electricity and Transportation Policy", International Council on Clean Transportation and Regulatory Assistance Project, July 2013
- Lowell, D. and Seamonds, D., "Supporting Passenger Mobility and Choice by Breaking Modal Stovepipes: Comparing Amtrak and Motor Coach Service", July 2013, American Bus Association Foundation
- Sharpe, B., Clark, N. and Lowell, D., "Trailer Technologies for increased heavy-duty vehicle efficiency: technical, market, and policy considerations", White Paper, International Council on Clean Transportation, June 2013
- Lowell, D., FMCSA-RRT-13-044, "Natural Gas Systems: Suggested Changes to Truck and Motor Coach Regulations and Inspection Procedures", Federal Motor Carrier Safety Administration, March 2013

- Lowell, D., Balon, T., Van Atten, C., Curry, T., Hoffman-Andrews, L., "Natural Gas for Marine Vessels: U.S. Market Opportunities", American Clean Skies Foundation, 2012
- Sharpe, B., Lowell, D., "Certification Procedures for Advanced Technology Heavy-Duty Vehicles: Evaluating Test Methods and Opportunities for Global Alignment", SAE International, SAE 201201-1986, 2012
- Lowell, D., "Clean diesel versus CNG buses: Cost, air quality, & climate impacts", Clean Air Task Force http://www.catf.us/resources/publications/files/20120227Diesel_vs_CNg_FINAL_MJBA.pdf, 2012
- Lowell, D. and Kamaketé, F., "Urban off-cycle NOX emissions from Euro IV/V trucks and buses: Problems and solutions for Europe and developing countries", White Paper No. 18, International Council on Clean Transportation, march 2012, http://www.theicct.org/urbancycle-nox-emissions-euro-ivv-trucks-and-buses
- Moynihan, P., Balon, B., Lowell, D., "NESCAUM Region 2 Marine Ferry and Tug Repower Project FINAL REPORT", NESCAUM, 2011
- Bongiovanni, R., "Chelsea Collaborative New England Produce Center TRU Electrification FINAL REPORT", Chelsea Collaborative, 2011
- Lowell, D., Seamonds, D., "Alternative Fueled Fleet Vehicle Analysis", Electric Power Research institute, EPRI 1023045, 2011
- Lowell, D., Curry, T., Hoffman-Andrews, L., Reynolds, L., "Comparison of Essential Air Service Program to Alternative Coach Bus Service: Keeping Rural Communities Connected", American Bus Association Foundation, September 2011
- Lowell, D., Balon, T., Danos, T., "Bus Technology & Alternative Fuels Demonstration Project Phase 4 Final Report", Greater Vancouver Transportation Authority, 2011
- Balon, T., Clark, N., Moynihan, P., Lowell, D., "Development of a Combined Oxidation System and Seawater Scrubber to Reduce Diesel NOx Emissions from Marine Engines Final Report", Houston Advanced Research Center, New Technology Research & Development Program N-40, 2011
- Balon, T., Moynihan, P., Lowell, D., Danos, T., Seamonds, D., "CSX Genset Switcher#1317 Locomotive Emission Testing FINAL REPORT", NESCAUM, 2010
- Park, D, Curry, T, Lowell, D., Balon, T.H., Piper, S, "Implications of Introducing Hydrogen Enriched Natural Gas in Gas Turbines", Atlantic Hydrogen, Inc, January 2010
- Lowell, D., Balon, T., Seamonds, D., Leigh, R., Silverman, I., "The Bottom of the Barrel: How the Dirtiest Heating Oil Pollutes Our Air and Harms Our Health", Environment Defense Fund, 2009
- Posada, F., Lowell, D. (editor), "CNG Bus Emissions Roadmap: from Euro III to Euro VI", international Council on Clean Transportation, 2009
- Lowell, D., "Lower Manhattan Construction, Construction Equipment Retrofit Case Study", Clean Air Task Force, 2009
- Lowell, D., Seamonds, D.G., "Evaluation of Vehicle Emissions Reduction Options for the Oil Sands Fleet", Environment Canada, March 2008
- Lowell, D., Balon, T.H., "Setting the Stage for Regulation of Heavy-Duty Vehicle Fuel Economy & GHG Emissions: Issues and Opportunities," International Council on Clean Transportation, March 2008
- Lowell, D., Balon, T. H., Danos, T. J., Moynihan, P.J., "Diesel Engine Retrofits in the Construction Industry: A How To Guide", Massachusetts Department of Environmental Protection, January 2008.
- Lowell, D., Balon, T., "Brooklyn Cruise Terminal Shore Power Feasibility Analysis", Port Authority of New York and New Jersey, 2008
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- Frank, B., Lanni, T., Lowell, D., Rosenblatt, D., Tang, S., "SAE 2003-01-0300, Evaluation of Compressed Natural Gas and Clean Diesel Buses at New York City's Metropolitan Transportation Authority", Society of Automotive Engineers, 2003
- Bush, C., Lowell, D., Parsley, W., Zupo, D., "A Comparison of Clean Diesel Buses to CNG Buses", Diesel Engine Emissions Reduction (DEER) Conference, US Department of Energy, Newport, RI, August 2003
- Bush, C., Chatterjee, S., Conway, R., Evans, J., Frank, B., Lanni, T., Levy, S., Lowell, D., Mclean, R., Rosenblatt, D., Tang, S., "SAE 2002-01-0430, Performance and Durability Evaluation of Continuously Regenerating Particulate Filters on Diesel Powered Urban Buses at NY City Transit – Part II", Society of Automotive Engineers, 2002
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- Lowell, D. "NYC Transit Shares Tricks of Maintaining Hybrids", BusTech Magazine, Summer 2000

**CURRICULUM VITAE**

**SHAWN W. MIDLAM-MOHLER, PH.D., P.E., P.M.P.**
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Columbus, Ohio 43212
(614) 307-4176
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## CURRENT APPOINTMENTS

**Assistant Professor of Practice – Primary Appointment** 8/2012 to present
Ohio State University Department of Mechanical and Aerospace Engineering, Columbus, OH

**Associate Director** 1/2014 to present
Ohio State University Simulation Innovation and Modeling Center, Columbus, OH

**OSU-CAR Associate Fellow** 8/2012 to present
Ohio State University Center for Automotive Research, Columbus, OH

**Director of OSU Motorsports** 7/2013 to present
Ohio State University College of Engineering, Columbus, OH

## PROFESSIONAL EXPERIENCE

**Research Scientist** 10/2008 to 7/2012
Ohio State University Center for Automotive Research, Columbus, OH

**Senior Research Associate** 11/2005 to 9/2008
Ohio State University Center for Automotive Research, Columbus, OH

**Research Associate II** 2/2004 to 10/2005
Ohio State University Center for Automotive Research, Columbus, OH

## EDUCATION

Ph.D. Mechanical Engineering 6/2005
The Ohio State University Columbus, OH
Dissertation Title: "Modeling, Control, and Diagnosis of a Diesel Lean $NO_x$ Trap Catalyst"

M.S. Mechanical Engineering 3/2001
The Ohio State University Columbus, OH
Thesis Title: "A Novel Fuel-Operated Heater for Automotive Thermal Management"

B.S. Mechanical Engineering *summa cum laude* 6/1999
Wright State University Dayton, OH

## PROFESSIONAL LICENSES

**Professional Engineer** License 75703
State of Ohio

**Project Management Professional** License 1622962
Project Management Institute

## RESEARCH EXPERIENCE

Dr. Midlam-Mohler maintains an active research program focused the area of Model-Based Design of Complex Systems. Research expenditures as PI/co-PI total more than $7 million.

Projects as PI / Co-PI:

| Start Date | Duration (Years) | Sponsor | Project Title |
|---|---|---|---|
| **8/2005** | 1.9 | Tenneco Automotive | Diesel Particulate Filter Regeneration with External Burner |
| **9/2005** | 3.3 | Tenneco Automotive | Reductant Generation for NOx Remediation |
| **3/2007** | 0.8 | Tenneco Automotive | Heavy duty Burner Prototypes and Control Development |
| **3/2007** | 3.8 | General Motors Corp | Development and implementation of a methodology, processes, and tools to produce a hierarchy of powertrain models that enable a math-based virtual design environment for powertrain control |
| **9/2007** | 1.6 | Nat Energy Tech Lab | Design and Fabrication of Diesel Fuel Atomizers |
| **1/2008** | 2.0 | Tenneco Automotive | Non-Catalytic Reformer Sensitivity Study and Prototype Development |
| **4/2008** | 4.0 | Cummins, Inc | Diesel Engine Combustion Control |
| **9/2008** | 3.0 | Department of Energy / General Motors | EcoCAR 1 Advanced Technology Vehicle Competition |
| **1/2009** | 3.0 | CAR PHEV Consortium | Fleet Studies and Transformer Modeling of PHEVs |
| **4/2009** | 2.3 | FirmGreen, Inc. | Landfill Gas Derived CNG Fuel Cycle Analysis |
| **4/2009** | 3.4 | Cummins, Inc | Cummins CIDI Engine Variability Measurements |
| **4/2009** | 2.5 | Stoneridge | Soot Sensor Testing and Soot Sensor Test Fixture |
| **9/2009** | 1.3 | Henkel Corp | Combustion Chamber Coating Evaluation |
| **5/2010** | 3.8 | Chrysler Group LLC | Advanced Technology Powertrains for Light-Duty Vehicles |
| **10/2010** | 2.0 | CAR Industrial Consortium | Lubricant Effects on Advanced Technology Vehicles |

| | | | |
|---|---|---|---|
| **8/2011** | 3.0 | Stoneridge | Fundamental Electrical Properties of Diesel Soot Films on a Diesel Soot Sensor |
| **9/2011** | 3.0 | Department of Energy / General Motors | EcoCAR 2 Advanced Technology Vehicle Competition |
| **8/2012** | 2.0 | Ctr for Trans. & Environment | ECO Saver IV Hybrid Electric Fuel Cell Bus Demonstration |
| **10/2012** | 2.0 | CAR Industrial Consortium | Gasoline Engine Particulate Matter Control |
| **1/2013** | 0.3 | Honda R&D Americas | Automated Vehicle Control using Low-Cost Sensors |
| **7/2013** | 0.5 | American Electric Power | Plug-In Electric Vehicle Data Analyses, Insights and Reports |
| **12/2013** | 2.0 | Chrysler Group LLC | Model-Based Optimization and Control Methodology for the Design of Chrysler's Next Generation Powertrain Control Systems |
| **9/2014** | 2.0 | Honda R&D Americas | Engine Startability Simulation, Modeling, and Control |
| **9/2014** | 2.0 | Honda R&D Americas | Model-Based Engine Calibration Techniques |
| **9/2014** | 1.7 | Chrysler Group LLC | Model-Based Particulate Filter Diagnosis and Control |
| **8/2014** | 4 | Department of Energy / General Motors | EcoCAR 3 Advanced Technology Vehicle Competition |

## TEACHING EXPERIENCE

**Undergraduate and Graduate Courses**

Dr. Midlam-Mohler has been involved in classroom education since 2007. His teaching focuses on automotive technical electives, capstone senior design, and most recently a course on project management and systems engineering.

| Period Offered | Course Number and Title (Credit Hours) |
|---|---|
| **Spring 2007** | ME 730 Internal Combustion Engine Modeling |
| **Winter 2009** | ME 631 Automotive Powertrain Laboratory |
| **Spring 2009** | ME 730 Internal Combustion Engine Modeling |
| **Winter 2010** | ME 631 Automotive Powertrain Laboratory |
| **Winter 2011** | ENGR 659.01 Multidisciplinary Capstone 1 |
| **Winter 2011** | ME 565.02 Mechanical Engineering Design 1 |
| **Winter 2011** | ME 631 Automotive Powertrain Laboratory |
| **Spring 2011** | ENGR 659.02 Multidisciplinary Capstone 2 |
| **Spring 2011** | ME 565.03 Mechanical Engineering Design 2 |
| **Winter 2012** | ENGR 659.01 Multidisciplinary Capstone 1 |
| **Winter 2012** | ME 565.02 Mechanical Engineering Design 1 |
| **Winter 2012** | ME 631 Automotive Powertrain Laboratory |
| **Spring 2012** | ENGR 659.02 Multidisciplinary Capstone 2 |

| | |
|---|---|
| **Spring 2012** | ME 565.03 Mechanical Engineering Design 2 |
| **Fall 2012** | ME 4902.01 Mechanical Engineering Capstone 1 |
| **Spring 2013** | ME 4902.02 Mechanical Engineering Capstone 2 |
| **Spring 2013** | ME 5531 Automotive Powertrain Laboratory |
| **Fall 2013** | ME 4902.01 Mechanical Engineering Capstone 1 |
| **Fall 2013** | ME 4194 Applied Project Management and System Engineering 1 (Pilot) |
| **Spring 2014** | ME 4902.02 Mechanical Engineering Capstone 2 |
| **Spring 2014** | ME 5531 Automotive Powertrain Laboratory |
| **Spring 2014** | ME 4194 Applied Project Management and System Engineering 2 (Pilot) |
| **Fall 2014** | ME 4902.02 Engineering Capstone |
| **Fall 2014** | ME 5194 Applied Project Management and System Engineering 1 |

**Distance Education Courses**

Dr. Midlam-Mohler is an active participant in the distance education program provided to General Motors through the Center for Automotive Research. He has also developed a number of courses in his area of expertise for the Department of Energy sponsored advanced technology vehicle competition program.

**Internal Combustion Engines from a System Perspective** 2014
Ohio State University, Columbus, OH
- Developed a 6 hour seminar from on IC engines from a systems perspective
- Supported by the Department of Energy

**IC Engine Modeling** 2014
Ohio State University, Columbus, OH
- Developed a 6 hour seminar from on modeling of internal combustion engines
- Supported by the Department of Energy

**Matlab for Data Analysis and Calibration Seminar** 2013
Ohio State University, Columbus, OH
- Developed a 10 hour seminar on the use of Matlab for data analysis and calibration
- Developed for the CAR Distance Education program

**SIL/HIL Techniques for Automotive Control Development** 2013
Ohio State University, Columbus, OH
- Developed a 10 hour seminar on the use of software-in-the-loop and hardware-in-the-loop techniques for control code validation and verification
- Developed for the CAR Distance Education program

**Model-Based Control of Hybrid Electric Vehicles** 2012
Ohio State University, Columbus, OH
- Developed a 6 hour seminar from on model-based control of hybrid vehicles
- Supported by the Department of Energy

**Alternative Fuels Seminar** 2013
Ohio State University, Columbus, OH
- Developed a 10 hour seminar on automotive alternative fuels
- Developed for the CAR Distance Education program

**Community Education**

**Invited Speaker for Public Events on Energy** 2009 - present
Various locations

- Invited speaker on energy and transportation at events such as: Automotive Engineering Career Panel, Charging Forward Conference, Green Energy Ohio, OSU College of Engineering Continuing Education Program, and the Moving Ahead Conference
- Involved in OSU College of Engineering Summer Camps

**Speaker for Groups Touring the Ohio State Center for Automotive Research** 2007 - present
Ohio State University Center for Automotive Research

- Provide 30 – 60 minute presentation and discussion on topic of energy use in transportation to groups
- Typically speak to >300 people per year on the topic of energy use in transportation

**Supervisor for EcoCAR Team Outreach Efforts** 2008 - present
Various locations

- Team is evaluated on ability to communicate information on transportation and energy to the general public, K-12 students, and influencers (i.e., industry leaders, government officials)
- Team has won numerous awards for outreach at the EcoCAR competition

**Graduate Student Advising and Supervision**

Dr. Midlam-Mohler has an active advising history of students earning advanced engineering degrees. This includes students enrolled at Ohio State as well as visiting scholars from outside of the institution.

**Doctoral Student (Co-Advisor)**

1. 2012 - Present Katherine Bovee. The Ohio State University.
2. 2014 - Present David Hillstrom. The Ohio State University.
3. 2014 - Present Bharat Hegde. The Ohio State University.

**Masters Student (Advisor)**

1. 2008 - 2009 Ming Fang. The Ohio State University.
2. 2008 - 2009 Rajaram Maringanti. The Ohio State University.
3. 2009 - 2010 Chris Hoops. The Ohio State University.
4. 2009 - 2010 Brad Cooley. The Ohio State University.
5. 2010 - 2011 Beth Bezaire. The Ohio State University.
6. 2010 - 2011 Ryan Everett. The Ohio State University.
7. 2010 - 2011 John Davis. The Ohio State University.
8. 2011 - 2012 Abhay Gupta. The Ohio State University.
9. 2011 - 2013 Andy Garcia. The Ohio State University.
10. 2012 - 2013 Saba Gurusubramanian. The Ohio State University.
11. 2012 - 2013 Teng Ma. The Ohio State University.
12. 2012 - 2013 Nithin Baradwaj. The Ohio State University.
13. 2012 - 2013 Steven Ramirez. The Ohio State University.
14. 2012 - 2014 Matt Organiscak. The Ohio State University.
15. 2012 - 2014 David Hilstrom. The Ohio State University
16. 2012 - 2014 Tamal Mukarjee. The Ohio State University.
17. 2011 - 2014 Amanda Hyde. The Ohio State University.
18. 2012 - 2014 Shreyas Shrivaprasad. The Ohio State University.
19. 2012 - 2014 Eric Gallo. The Ohio State University.
20. 2013 - 2014 David Hillstrom. The Ohio State University.
21. 2013 - 2014 Bharat Hedge. The Ohio State University.
22. 2012 - Present Andrew Spiegal. The Ohio State University.
23. 2013 - Present Benjamin Stumpf. The Ohio State University
24. 2013 - Present Jason Ward. The Ohio State University.
25. 2013 - Present Samuel Yacinthe. The Ohio State University.

26. 2014 - Present Aaron Bonnell-Kangas. The Ohio State University.
27. 2014 - Present Luke Cardinale. The Ohio State University.
28. 2014 - Present James Mack. The Ohio State University.

**Masters Student (Co-Advisor)**

1. 2004 - 2005 Eric Snyder. The Ohio State University.
2. 2005 - 2006 Courtney Coburn. The Ohio State University.
3. 2005 - 2006 Adam Vosz. The Ohio State University.
4. 2006 - 2007 Josh Cowgill. The Ohio State University.
5. 2006 - 2007 Kenny Follen. The Ohio State University.
6. 2011 - 2012 Katherine Bovee. The Ohio State University.
7. 2011 - 2014 Matt Yard. The Ohio State University.

**Undergraduate Research (Advisor)**

1. 2006 - 2007 Rhisee Bhatt. The Ohio State University.
2. 2008 - 2009 Chris Hoops. The Ohio State University.
3. 2009 - 2010 Ryan Everett. The Ohio State University.
4. 2009 - 2010 John Davis. The Ohio State University.
5. 2009 - 2010 Katherine Bovee. The Ohio State University.
6. 2012 - 2013 Jason Ward. The Ohio State University.
7. 2012 - 2013 Andrew Speigel. The Ohio State University.
8. 2013 - 2014 MJ Yatsko. The Ohio State University.
9. 2013 - 2014 Gaurav Krishnaraj. The Ohio State University.
10. 2012 - Present Arjun Khanna. The Ohio State University.

**Senior Capstone Group Advising**

Dr. Midlam-Mohler has been actively involved in the advising of student capstone design projects which typically span 1.5 semesters. In these projects, small groups of students are required to design, build, and test a prototype. In Dr. Midlam-Mohler's courses, each group works on a different project.

- AY 2011-2012: Four Capstone Groups Advised
- AY 2012-2013: Five Capstone Groups Advised
- AY 2013-2014: Seven Capstone Groups Advised

**Student Organization Advising**

**EcoCAR 2 Hybrid Electric Vehicle Team** 7/2011 – 6/2014
Ohio State University, Columbus, OH

- Serve as lead co-adviser of a 40 member (~80% undergraduate) student design project team competing in U.S. Department of Energy sponsored vehicle competition
- Supervised the student-led preparation of the top-ranked proposal for entry into the competition
- The team finished 2nd place in the first year of competition, 3rd place in the second year, and 1st place the final year of the competition

**EcoCAR Challenge Hybrid Electric Vehicle Team** 6/2008 – 6/2011
Ohio State University, Columbus, OH

- Served as lead co-adviser of a 40 member (~80% undergraduate) student design project team competing in U.S. Department of Energy sponsored vehicle competition
- Team won 1st, 5th, and 2nd in the three years of competition and won numerous event awards

**Challenge-X Hybrid Electric Vehicle Team** 8/2006 – 6/2008
Ohio State University, Columbus, OH

- Co-advised primarily undergraduate team competing in a U.S. Department of Energy sponsored advanced technology vehicle competition
- Over the course of the four year competition from 2004 – 2008, OSU placed 3rd, 4th, 4th, and 3rd respectively

**High School Students Mentoring**

Dr. Midlam-Mohler has mentored six local high school students for ~30 hours of activity per student since 2007. These students have been from the Hilliard School District's mentorship program.

## INTERNAL SERVICE

**Automotive Graduate Specialization Committee Member** 2013 to present
Ohio State University, Columbus, OH

- Played lead-role in remapping graduate specialization from quarters to semesters

**Graduate Admissions Committee** 2012 to present
Ohio State University, Columbus, OH

- On committee which reviews graduate student applications and recommends acceptance to the Department and consideration for Department and University fellowships

**CAR Facilities Planning Team Member** 2012 to present
Ohio State University, Columbus, OH

- Participate in team dealing with space and facilities issues at the Center for Automotive Research

**ME Design Faculty Curriculum Team Member** 2011 to present
Ohio State University, Columbus, OH

- Participate in faculty group responsible or capstone design experience in ME

**CoE Design Faculty Curriculum Team Member** 2011 to present
Ohio State University, Columbus, OH

- Participate in faculty group coordinating the capstone design experience across the College

## EXTERNAL SERVICE

**EcoCAR 2 Faculty Advisory Board**
Board Member 8/2011 to 7/2012 and 8/2013 to present

- Work with EcoCAR 2 competition staff , General Motors staff, and four other EcoCAR 2 team advisors to improve the student design experience for the EcoCAR 2 competition
- Elected to the position by a vote of the EcoCAR 2 faculty advisors

**Clean Fuels Ohio,** Columbus, OH 9/2009 to 5/2013
Member of the Board of Directors

- Elected to Board of Directors of Clean Fuels Ohio, a non-profit committed to cleaner transportation fuels which is part of the U.S. Department of Energy Clean Cities program
- Served as Secretary and member of the Executive Committee for the organization

**Publication Reviewer** 2005 to present

- Review numerous publications for conferences and journal submissions to ASME, SAE, IEEE, *etc.*

## PAID EXTERNAL CONSULTING

**EPA Automotive Technology Policy Report Reviewer**, Columbus, OH
Peer Reviewer 6/2012

- Conducted a compensated peer review of a study of future light-duty vehicle technology used in making policy decisions for future fuel-economy regulations.

**EPA Light-Duty Vehicle Model Reviewer**, Columbus, OH
Peer Reviewer 6/2011

- Conducted a compensated peer review of a study of future light-duty vehicles for the U.S. EPA used for guiding future fuel economy and greenhouse gas emissions regulations

**EPA GEM Model Reviewer**, Columbus, OH
Peer Reviewer 12/2010

- Conducted a compensated peer review of a heavy-duty truck model developed by the U.S. EPA used for predicting fuel economy and greenhouse gas emissions

**State of Indiana** 4/2009
Proposal Reviewer

- Reviewed multi-million dollar proposal for Indiana grant program in area of internal combustion engines

**McMaster Fuel Ltd.**, Perrysburg, OH 9/2006 to 1/2007
Independent Consultant

- Provided analysis of a hydrogen production technique against other methods of hydrogen production
- Assisted McMaster Fuel Ltd. in making strategic decisions regarding their technology

## AWARDS

**Applied Automotive Engineering Fellow - Department of Energy** 10/2013

- Presented to a acknowledge significant contributions to applied automotive engineering research and education

**Outstanding Technology Team – TechColumbus** 2/2012

- Presented to a team of OSU-CAR faculty and research staff because of their extensive partnerships driving technology forward in Ohio

**National Science Foundation Outstanding Incoming Faculty Advisor Award** 7/2011

- Presented to the junior EcoCAR faculty advisor who best promotes the goals, objectives, and activities related to the EcoCAR student design competition

## INTELLECTUAL PROPERTY

1. Rajagopalan, Sai SV, Kenneth P. Dudek, Sharon Liu, Stephen Yurkovich, Shawn W. Midlam-Mohler, Yann G. Guezennec, and Yiran Hu. "Universal tracking air-fuel regulator for internal combustion engines." U.S. Patent

8,571,785, issued October 29, 2013.

2. Midlam-Mohler, S., Meyer, J., Yurkovich, S., & Sujan, V. (2012). U.S. Patent Application 13/479,568
3. J. Meyer, S. Midlam-Mohler, K. Dudek, S. Yurkovich, Y. Guezennec, "Fuel control system and method for more accurate response to feedback from an exhaust system with an air/fuel equivalence ratio offset", U.S. Patent 8,347,866, awarded January 8, 2013.
4. S. Midlam-Mohler, S. Rajagoplan, K. Dudek, S. Yurkovich, Y. Guezennec, "Compensating for random catalyst behavior", 8,346,458, January 1, 2013.
5. J. Meyer, S. Midlam-Mohler, K. Dudek, S. Yurkovich, Y. Guezennec, "Delay calibration systems and methods", U.S. Patent 8,265,858, awarded September 11, 2012.
6. S. Rajagolalan, J. Meyer, S. Midlam-Mohler, K. Dudek, S. Yurkovich, Y. Guezennec "Control systems and methods using geometry based exhaust mixing model", U.S. Patent 8,224,557, awarded July 17, 2012.
7. J. Meyer, S. Midlam-Mohler, K. Dudek, S. Yurkovich, Y. Guezennec, "Fuel control system and method for improved response to feedback from an exhaust system", U.S. Patent 8,186,336, awarded May 29, 2012.
8. J. Meyer, S. Midlam-Mohler, K. Dudek, S. Yurkovich, Y. Guezennec, "Delay compensation systems and methods", U.S Patent 8,113,187, awarded 2/12/2012.
9. Y. Hu, K. Dudek, S. Midlam-Mohler, Y. Guezennec, S. Yurkovich, L. Wiggins, "System and method for determining a camshaft position in a variable valve timing engine", U.S. Patent 8,096,271, awarded 1/17/2012.
10. S. Liu, K. Dudek, S. Rajagoplan, S. Yurkovich, Y. Hu, Y. Guezennec, S. Midlam-Mohler, "Off-line calibration of universal tracking air fuel ratio regulators", U.S. Patent 7,925,421, awarded 4/12/2011.
11. K. Dudek, S. Rajagoplan, S. Yurkovich, Y. Hu, Y. Guezennec, S. Midlam-Mohler, L. Avallone, I. Anilovich, "Air fuel ratio control system for internal combustion engines", U.S. Patent 7,937,209, awarded 5/3/2011.
12. S. Midlam-Mohler, B. Masterson, "System System for Controlling NOx Emissions during Restarts of Hybrid and Conventional Vehicles," U.S. Patent 7,257,493, awarded 3/21/07.
13. S. Midlam-Mohler, "System and Method for Reducing NOx Emissions after Fuel Cut-Off Events," U.S. Patent 7,051,514, awarded 5/30/06.

## PUBLICATIONS

### Journal Articles

1. Hyde, A., Midlam-Mohler, S., and Rizzoni, G., "Development of a Dynamic Driveline Model for a Parallel-Series PHEV," SAE Int. J. Alt. Power. 3(2):244-256, 2014, doi: 10.4271/2014-01-1920. 2014.
2. Rajagopalan, S. S., Midlam-Mohler, S., Yurkovich, S., Dudek, K. P., Guezennec, Y. G., & Meyer, J. "A control design and calibration reduction methodology for AFR control in gasoline engines", Control Engineering Practice, 27, 42-53. 2014.
3. Q. Gong, S. Midlam-Mohler, V. Marano, G. Rizzoni, "Statistical Analysis for PHEV Virtual Fleet Study", International Journal of Vehicle Design, Vol. 58, Nos. 2/3/4, 2012.
4. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, and Giorgio Rizzoni. "Virtual PHEV fleet study based on Monte Carlo simulation." *International Journal of Vehicle Design* 58, no. 2–4 (2012): 266–290. doi:10.1504/IJVD.2012.047388.
5. B. Cooley, D. Vezza, S. Midlam-Mohler, G. Rizzoni, "Model Based Engine Control Development and Hardware-in-the-Loop Testing for the EcoCAR Advanced Vehicle Competition", SAE International Journal on Engines, Vol. 4, No. 1, pp. 1699 -1707, 2011.
6. Meyer, Jason,A; Yurkovich,Stephen; Midlam-Mohler,Shawn. "A Model Based Estimator for Cylinder Specific Air-to-Fuel Ratio Corrections." JOURNAL OF DYNAMIC SYSTEMS MEASUREMENT AND CONTROL-TRANSACTIONS OF THE ASME. Vol. 133, no. 3. (May 2011): 031001.
7. Q. Gong, S. Midlam-Mohler, V. Marano, G. Rizzoni, "An Iterative Markov Chain Approach for Generating Vehicle Drive Cycles", SAE International Journal on Engines, Vol. 4, No. 1, pp. 1035-1045, 2011.
8. M. Canova, S. Midlam-Mohler, P. Pisu, A. Soliman, "Model-Based Fault Detection and Isolation for a Diesel Lean NOx Trap Aftertreatment System," Control Engineering Practice, November 2009.

9. M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Mean Value Modeling and Analysis of HCCI Diesel Engines with External Mixture Formation," ASME Journal of Dynamic Systems, Measurement and Control, Vol. 131, No. 11, 2009.
10. M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Theoretical and Experimental Investigation on Diesel HCCI Combustion with External Mixture Preparation," International Journal of Vehicle Dynamics, Volume 44, Nos 1-2, 2007.
11. N. Szabo, C. Lee, J. Trimboli1, O. Figueroa, R. Ramamoorthy, S. Midlam-Mohler, A. Soliman, H. Verweij, P. Dutta and S. Akbar, "Ceramic-Based Chemical Sensors, Probes and Field-Tests in Automobile Engines," Journal of Materials Science, November, 2003.

**Conference Papers**

1. Bovee, K., Hyde, A., Yatsko, M., Yard, M., Organiscak, M., Gallo, E. ... & Midlam-Mohler, S. W., "Refinement of a Parallel-Series PHEV for Year 3 of the EcoCAR 2 Competition", SAE Technical Paper 2014-01-2908, 2014.
2. Alley, Robert Jesse, Patrick Walsh, Nicole Lambiase, Brian Benoy, Kristen De La Rosa, Douglas Nelson, Shawn Midlam-Mohler, Jerry Ku, and Brian Fabien. "ESS Design Process Overview and Key Outcomes of Year Two of EcoCAR 2: Plugging in to the Future." SAE Technical Paper, 2014.
3. Hyde, Amanda, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Development of a Dynamic Driveline Model for a Parallel-Series PHEV." SAE Technical Paper, 2014.
4. Bovee, K., Hyde, A., Yard, M., Gallo, E., Garcia, A., Organiscak, M., Midlam-Mohler, S. W. & Rizzoni, G., "Fabrication of a Parallel-Series PHEV for the EcoCAR 2 Competition" ,SAE Technical Paper 2013-01-2491, 2013.
5. Gong, Q., S. Midlam-Mohler, E. Serra, V. Marano, and G. Rizzoni. "PEV charging control for a parking lot based on queuing theory." In *American Control Conference (ACC), 2013*, pp. 1124-1129. IEEE, 2013.
6. Meyer, Jason, Stephen Yurkovich, and Shawn Midlam-Mohler. "Air-to-Fuel Ratio Switching Frequency Control for Gasoline Engines." In *Control Systems Technology, IEEE Transactions on*, 21:636–48, 2013.
7. Bezaire, Beth, and Shawn Midlam-Mohler. "A Physically-Based, Lumped-Parameter Model of an Electrically-Heated Three-Way Catalytic Converter." SAE Technical Paper, 2012.
8. Bovee, Katherine, Amanda Hyde, Shawn Midlam-Mohler, Giorgio Rizzoni, Matthew Yard, Travis Trippel, Matthew Organiscak, et al. "Design of a Parallel-Series PHEV for the EcoCAR 2 Competition." SAE Technical Paper, 2012.
9. Bovee, Katherine, Amanda Hyde, Travis Trippel, Vignesh Vimalesan, Sabarish Gurusubramanian, Kishore Kumaraswamy Sai, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Rapid Vehicle Architecture Selection With Use of Autonomie." In *ASME 2012 5th Annual Dynamic Systems and Control Conference Joint with the JSME 2012 11th Motion and Vibration Conference*, 119–28. American Society of Mechanical Engineers, 2012.
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12. Gong, Q., S. Midlam-Mohler, E. Serra, V. Marano, and G. Rizzoni. "Distribution Transformer Tests for PEV Smart Charging Control." In *Energytech, 2012 IEEE*, 1–6. IEEE, 2012.
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14. Q. Gong, S. Midlam-Mohler, V. Marano, G. Rizzoni, "Optimal Control of PEV Charging Based on Residential Base Load Prediction", ASME Dynamic Systems and Control Conference (DSCC), 2011.
15. J. Meyer, S. Midlam-Mohler, S. Yurkovich, "In-cylinder Oxygen Concentration Estimation for Diesel Engines Via Transport Delay", American Control Conference, 2011.
16. K. Follen, M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, B. Lee, G. Matthews, "A High Fidelity Lumped-Parameter Engine Model for Powertrain Control Design and Validation.", ASME Dynamic Systems and Control Conference, Cambridge, MA, United States, 2011.

17. Cooley, Robert, Davide Vezza, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Model Based Engine Control Development and Hardware-in-the-Loop Testing for the EcoCAR Advanced Vehicle Competition." SAE Technical Paper, 2011.
18. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, and Giorgio Rizzoni. "An Iterative Markov Chain Approach for Generating Vehicle Driving Cycles." SAE Technical Paper, 2011.
19. Gong, Q., S. Midlam-Mohler, V. Marano, and G. Rizzoni. "PEV Charging Impact on Residential Distribution Transformer Life." In *Energytech, 2011 IEEE*, 1–6. IEEE, 2011.
20. Gong, Q., P. Tulpule, V. Marano, S. Midlam-Mohler, and G. Rizzoni. "The Role of ITS in PHEV Performance Improvement." In *American Control Conference (ACC), 2011*, 2119–24. IEEE, 2011.
21. Marano, V., P. Tulpule, Q. Gong, A. Martinez, S. Midlam-Mohler, and G. Rizzoni. "Vehicle Electrification: Implications on Generation and Distribution Network." In *Electrical Machines and Systems (ICEMS), 2011 International Conference on*, 1–6. IEEE, 2011.
22. Meyer, Jason, Shawn Midlam-Mohler, and Stephen Yurkovich. "In-Cylinder Oxygen Concentration Estimation for Diesel Engines via Transport Delay Modeling." In *American Control Conference (ACC), 2011*, 396–401. IEEE, 2011.
23. Bayar, Kerem, Beth Bezaire, Brad Cooley, John Kruckenberg, Eric Schacht, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Design of an Extended-Range Electric Vehicle for the EcoCAR Challenge." In *ASME 2010 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 687–700. American Society of Mechanical Engineers, 2010.
24. Follen, K., M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, B. Lee, and G. Matthews. "A High Fidelity Lumped-Parameter Engine Model for Powertrain Control Design and Validation." In *ASME 2010 Dynamic Systems and Control Conference*, 695–702. American Society of Mechanical Engineers, 2010.
25. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, Giorgio Rizzoni, and Yann Guezennec. "Statistical Analysis of Phev Fleet Data." In *Vehicle Power and Propulsion Conference (VPPC), 2010 IEEE*, 1–6. IEEE, 2010.
26. Meyer, Jason, Stephen Yurkovich, and Shawn Midlam-Mohler. "Architectures for Phase Variation Compensation in AFR Control." In *American Control Conference (ACC), 2010*, 1447–52. IEEE, 2010.
27. R. Maringanti, S. Midlam-Mohler, M. Fang, F. Chiara, M. Canova, "Set-Point Generation using Kernel-Based Methods for Closed-Loop Combustion Control of a CIDI Engine," ASME DSCC2009, September, 2009.
28. J. Meyer, S. Rajagopalan, S. Midlam-Mohler, Y. Guezennec, S. Yurkovich, "Application of an Exhaust Geometry Based Delay Prediction Modal to an Internal Combustion Engine," ASME DSCC2009, September, 2009.
29. M. Fang, S. Midlam-Mohler, R. Maringanti, F. Chiara, M. Canova, "Optimal Performance of Cylinder-by-Cylinder and Fuel Bank Controllers for a CIDI Engine," ASME DSCC2009, September, 2009.
30. S. Midlam-Mohler, E. Marano, S. Ewing, D. Ortiz, G. Rizzoni, "PHEV Fleet Data Collection and Analysis," IEEE VPPC09, September 2009.
31. L. Headings, G. Washington, S. Midlam-Mohler, J. Heremans, "Thermoelectric Power Generation for Hybrid-Electric Vehicle Auxiliary Power," Proc. SPIE Int. Conference on Smart Structures and Materials, 2009, Vol. 7290, No. 13.
32. L. Headings, G. Washington, S. Midlam-Mohler, and J. Heremans, "High temperature multi-fuel combustion-powered thermoelectric auxiliary power unit", Proceedings of SMASIS2009: ASME 2009 Conference on Smart Materials, Adaptive Structures and Intelligent Systems, Oxnard, CA, USA, ASME, 123-130.
33. M. Canova, S. Midlam-Mohler, G. Rizzoni, F. Steimle, D. Boland, M. Bargende, "A Simulation Study of an E85 Engine APU for a Series Hybrid Electric Vehicle," 9th Stuttgart International Symposium on Automotive and Engine Technology, Stuttgart, Germany, 2009.
34. K. Koprubasi, A. Pezzini, B. Bezaire, R. Cooley, P. Tulpule, G. Rizzoni, Y. Guezennec, S. Midlam-Mohler, "Application of Model-Based Design Techniques for the Control Development and Optimization of a Hybrid-Electric Vehicle", SAE World Congress 2009, Detroit, MI.
35. S. Rajagopalan, S. Midlam-Mohler, S. Yurkovich, Y. Guezennec, K. Dudek, "Control Oriented Modeling of a Three Way Catalyst Coupled with Oxygen Sensors," ASME Dynamic System and Controls Conference, Ann Arbor, MI, 2008.
36. L. Headings, S. Midlam-Mohler, G. Washington, and J. P. Heremans, "High Temperature Thermoelectric Auxiliary Power Unit for Automotive Applications," ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, 2008, Paper #610.
37. K. Sevel, M. Arnett, K. Koprubasi, C. Coburn, M. Shakiba-Heref, K. Bayar, G. Rizzoni, Y. Guezennec, S. Midlam-Mohler, "Cleaner Diesel Using Model-Based Design and Advanced Aftertreatment," SAE 2008-01-0868, 2008 International Congress, Detroit, MI, April 2008.

38. K. Dudek, B. Montello, J. Meyer, S. Midlam-Mohler, Y. Guezennec, and S. Yurkovich, "Rapid Engine Calibration for Volumetric Efficiency and Residuals by Virtual Engine Mapping," International Congress on Virtual Power Train Creation 2007, Munich, Germany, October 24-25, 2007.
39. M. Canova, S. Midlam-Mohler, Y. Guezennec, A. Soliman, and G. Rizzoni, "Control-Oriented Modeling of NOx Aftertreatment Systems," SAE ICE'07 Conference, Capri, Italy, September 2007.
40. M. Canova, F. Chiara, J. Cowgill, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Experimental Characterization of Mixed-Mode HCCI/DI Combustion on a Common Rail Diesel Engine," 8th International Conference on Engines for Automobile (ICE2007), Capri, Italy.
41. M. Canova, F. Chiara, M. Flory, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Experimental Characterization of Mixed Mode HCCI/DI Combustion on a Common Rail Diesel Engine," submitted to SAE ICE'07 Conference, Capri, Italy, September 2007.
42. M. Canova, M. Flory, Y. Guezennec, S. Midlam-Mohler, G. Rizzoni, and F. Chiara, "Dynamics and Control of DI and HCCI Combustion in a multi-cylinder Diesel engine," Paper 44, submitted to 5th IFAC Symposium on Advances in Automotive Control, Pajaro Dunes/Seascape, CA, August 2007.
43. A. Vosz, S. Midlam-Mohler, and Y. Guezennec, "Experimental Investigation of Switching Oxygen Sensor Behavior Due to Exhaust Gas Effects," Proc. of IMECE '06, Paper IMECE 2006-14915, Chicago, IL, November 2006.
44. S. Midlam-Mohler and Y. Guezennec, "A Temperature-Based Technique for Temporally and Spatially Resolved Lean NOx Trap Catalyst NOx Measurements," Proc. of IMECE '06, Paper IMECE 2006-14887, Chicago, IL, November 2006.
45. M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, L. Garzarella, M. Ghisolfi, and F. Chiara, "Experimental Validation for Control-Oriented Modeling of Multi-Cylinder HCCI Diesel Engines," Proc. of IMECE '06, Paper IMECE 2006-14110, Chicago, IL, November 2006.
46. A. Soliman, S. Midlam-Mohler, Z. Zou, Y. Guezennec, and G. Rizzoni, "Modeling and Diagnostics of NOx Aftertreatment Systems," Proc. FISITA '06, Yokohama, Japan, October 2006.
47. Z. Zou, S. Midlam-Mohler, R. Annamalai, Y. Guezennec, V. Subramaniam, "Literature Survey of On-Board Hydrogen Generation Methods for Diesel Powertrains," Global Powertrain Conference, Novi, MI, Not Peer Reviewed, September 2006.
48. K. Follen, S. Midlam-Mohler, Y. Guezennec, "Diesel Particulate Filter Regeneration with an External Burner," Global Powertrain Conference, Novi, MI, Not Peer Reviewed, September 2006.
49. S. Midlam-Mohler and Y. Guezennec, "Regeneration Control for a Bypass-Regeneration Lean NOx Trap System," American Control Conference '06, Minneapolis, MN, Invited paper, June 2006.
50. A. Soliman, I. Choi, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Modeling and Diagnostics of NOx After-Treatment Systems," SAE Paper 2006-05-0208, 2006 International Congress, Detroit, MI, April 2006.
51. S. Midlam-Mohler and Y. Guezennec, "Design, Modeling and Validation of a Flame Reformer for LNT External By-Pass Regeneration," SAE Paper 2006-01-1367, 2006 SAE International Congress, Detroit, MI, April 2006.
52. S. Midlam-Mohler, and Y. Guezennec, "Modeling of a Partial Flow Diesel, Lean NOx Trap System," Proc. of IMECE '05, Paper IMECE 2005-80834, Orlando, FL, November 2005.
53. M. Canova, L. Garzarella, M. Ghisolfi, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "A Control-Oriented Mean-Value Model of HCCI Diesel Engines with External Mixture Formation," Proc. of IMECE '05, Paper IMECE 2005-79571, Orlando, FL, November 2005.
54. A. Soliman, P. Jackson, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "Diagnosis of a NOx Aftertreatment System," ICE 2005 7th International Conference on Engines for Automobiles, Capri, Italy, September 2005.
55. M. Canova, L. Garzarella, M. Ghisolfi, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "A Mean-Value Model of a Turbo-Charged HCCI Diesel Engine with External Mixture Formation," ICE 2005 7th International Conference on Engines for Automobiles, Capri, Italy, September 2005.
56. M. Canova, R. Garcin, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "A Control-Oriented Model of Combustion Process in HCCI Diesel Engines," American Control Conference '05, Portland, OR, June 2005.
57. C. Musardo, B. Staccia, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "Supervisory Control for NOX Reduction of an HEV with a Mixed-Mode HCCI/CIDI Engine," American Control Conference '05, Portland, OR, June 2005.
58. M. Canova, A. Vosz, D. Dumbauld, R. Garcin, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "Model and Experiments of Diesel Fuel HCCI Combustion with External Mixture Formation," 6th Stuttgart International Symposium on Motor Vehicles and Combustion Engines, Stuttgart, Germany, Not peer reviewed, February 2005.

59. S. Midlam-Mohler, S. Haas, Y. Guezennec, M. Bargende, G. Rizzoni, S. Haas, and H. Berner, "Mixed-Mode Diesel HCCI/DI with External Mixture Preparation," Paper F2004V258, Proc. FISITA '04 World Congress, Barcelona, Spain, May 2004.
60. Y. Guezennec, C. Musardo, B. Staccia, S. Midlam-Mohler, E. Calo, P. Pisu, and G. Rizzoni, "Supervisory Control for NOx Reduction of an HEV with a Mixed-Mode HCCI/DI Engine," Paper F2004F233, Proc. FISITA '04 World Congress, Barcelona, Spain, May 2004.
61. M. Gilstrap, G. Anceau, C. Hubert, M. Keener, S. Midlam-Mohler, K. Stockmeier, J-M Vespasien, Y. Guezennec, F. Ohlemacher, and G. Rizzoni, "The 2002 Ohio State University FutureTruck – The BuckHybrid002," 2003 SAE International Congress and Exposition, Detroit, MI, March 2003.
62. Y. Guezennec, S. Midlam-Mohler, M. Tateno, and M, Hopka, "A 2-Stage Approach to Diesel Emission Management in Diesel Hybrid Electric Vehicles," Proc. 2002 IFAC Meeting, Barcelona, Spain, July 2002.
63. M. Hopka, A. Brahma, Q. Ma, S. Midlam-Mohler, G. Paganelli, Y. Guezennec, and G. Rizzoni, "Design, Development and Performance of Buckeyebrid: The Ohio State Hybrid Electric FutureTruck 2001," SAE SP-1701, Not peer reviewed, March 2002.

# Susan Nelson

Greenville, South Carolina

Project Management and Technical Consulting Services
Focus: Transportation Technology and Energy Efficiency

## Career Highlights

- Management of projects in technical, research, and policy investigations, comprised of interdisciplinary and inter-organizational participants from corporate, national laboratory, university and regulatory areas.
- Facilitation of team and stakeholder groups to clarify and obtain consensus on business needs, project scope and objectives, solution development and ranking, and management of risks.
- Over 14 years of research and development experience for heavy trucks, including direct product development and validation in the North American, European, and Japanese markets, with additional light duty component development for global market approvals.
- Direct experience in heavy truck fleets to optimize selection and use of fuel-efficient technologies and evaluation methods. Planning and participation in joint testing at fleet test sites.

## Current Position – Owner and Managing Member - Blue Stripe Scientific, LLC – Greenville, SC

- Acquired ownership and management of Blue Stripe Scientific, LLC in 2012. Updated the business focus to include project management in addition to technical consulting in research and development.
- Project Manager and technical service provider to assess approaches to monitor and maintain inflation pressure in heavy duty vehicle tires, under contract to the North American Council for Freight Efficiency (NACFE). Defined categories of technologies to permit characterization of diverse product offerings according to common features and functionalities. Conducted and analyzed stakeholder input data through face-to-face and telephone interviews, and through Internet surveys developed specifically for the project. Project deliverables include a final report, a technology payback calculator, and a matrix summary of the various tire pressure technologies together with their primary functional characteristics, advantages, and limitations. Results are publicly available at nacfe.org/projects.

## Relevant Prior Professional Experience

*Michelin North America – Michelin America's Research Company, Greenville, South Carolina*

### Senior Principal Project Manager, 2009-2011 – Heavy Truck Tire Product Line

- Led two cross-functional research teams (32 members) in high-profile, multi-phase projects for development of six new long haul, heavy truck tire lines, including next generation fuel-efficient products, for delivery to the corporate business team. Set strategic technical direction of the projects, and managed the planning, scheduling, budget, and stakeholder requirements – including liaison with marketing and sales, research and operational technical directors, corporate level quality, functional managers, and global level portfolio managers. Responsible for project level reporting and analysis of performance indicators, including synthesis of team reports and presentations.
- Project lead for Michelin's participation in the Navistar-led DOE SuperTruck project. Activated a sub-team of 4 of the 9 participating organizations for collaborative redesign of truck axle and wheel-end components. Enabled and participated in inter-company track testing using SAE Type II fuel economy test methods.

### Senior Project Leader, 2008-2009

- Project and technical lead for two exploratory projects in heavy truck tire fuel efficiency and long-term endurance performance using emerging materials and design technologies.
- Michelin technical liaison to EPA SmartWay program.
- Directed Michelin participation in research study of heavy truck rollover sensitivity with university and national laboratory partners in conjunction with the National Transportation Research Center, Inc. Publication of evaluations/recommendations for a Class 8 tractor in combination with flatbed, box, and tanker trailers.

### Manager -Truck Tire Innovation and Endurance Research Team, 2006-2008

- Managed team of project engineers, finite element simulation analysts, and manufacturing engineers for product innovation, test and test systems development, and fleet placement and tracking of long-term tire performance from clean-sheet conception through physical prototype stage.

- Responsible for streamlining cycles of prototype development and testing.
- Provided industry advice and support to Oak Ridge National Laboratory multi-year field operational test of impact of tire rolling resistance on heavy truck fuel consumption.

## Susan Nelson – Page 2

### Supplemental Work Experience

**Michelin North America and Michelin France 1985-2006.** Engineer in both OE passenger car and heavy truck tire development, vehicle vibration analysis, and quality and manufacturing processes. Development engineer for heavy duty tire products in the North American, European, and Japanese markets. Development engineer for light duty products destined for global markets, subject to OEM and internal Michelin performance specifications, and country specific regulatory requirements.

**Tennessee Valley Authority 1979-1985, Norris, Tennessee.** Water Resources/Civil Engineer responsible for TVA river flow and power plant effluent computer simulations and field validation, including response planning for potential emergency incidents at nuclear facilities.

### Education – Massachusetts Institute of Technology, Cambridge, Massachusetts

1977 Bachelor of Science, Civil Engineering
1979 Master of Science, Civil Engineering – Master's thesis program in fluid dynamics and environmental engineering

### Certifications and Professional Affiliations

Professional Engineer (PE), 1982 – Present
Certified Quality Engineer (CQE), 1989 – Present
Project Management Professional (PMP), 2012 - Present
American Trucking Associations Technology & Maintenance Council
Society of Automotive Engineers
American Society for Quality Senior Member
Sigma Xi, Scientific Research Society

### Publications and Joint Research

E. Johnson, S. Nelson, F. Marlier, S. Nicolas, and M. Rolland, "Optimized Drive Axle Design for Class 8 Tractors Equipped with New Generation Wide Base Single Tires" SAE Technical Paper 2009-01-2861, October 6, 2009.

D. Pape, M. Arant, S. Nelson, O. Franzese, H. Knee, T. LaClair, U. Attanayake, R. Hathaway, M. Keil, and K. Ro,"Heavy Truck Rollover Characterization (Phase B) Final Report", Study funded by the National Transportation Research Center under a grant from the U.S. Department of Transportation Research and Innovative Technology Administration (#DTRT06G-0043), September 2009.

M. Arant, D. Hall, S. Nelson, R. Hathaway, M. Keil, P. Pollock, O. Franzese, H. Knee, N. Wood, D. Pape, J. Petrolino, S. Yeakel, "Heavy Truck Rollover Characterization (Phase A) Final Report" (NTRCI-50-2008-006), Study funded by the National Transportation Research Center under a grant from the U.S. Department of Transportation Research and Innovative Technology Administration (#DTRT06G-0043), September 2008.

G.J. Capps, O. Franzese, H.E. Knee, M.B. Lascurain and P. Otaduy,"Class-8 Heavy Truck Duty Cycle Project Final Report" ORNL/TM-2008/122, Oak Ridge National Laboratory, Oak Ridge, TN (2008).

### Presentations

"Truck Tires and Rolling Resistance", presented February 2009 as representative of Michelin Americas Research Company to the National Academy of Sciences Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles. Presentation materials including range of common tire rolling resistance levels as well as simulation results of the effect of tire rolling resistance on fuel economy over various drive cycles were included in the Committee's March 2010 report,

"Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles", ISBN: 978-0-309-14982-2.

"Wide Thing: A Case Study of Innovating in a Mature Market", Susan Nelson, Michelin Americas Research Company, Front End of Innovation (FEI) Conference, Boston, MA, May 20-21, 2008.

"Improving Test Practices for Fuel Economy Evaluations of Heavy Trucks", Susan Nelson, Michelin Americas Research Company, presented at the 23rd Annual Clemson University Tire Industry Conference, March 14-16, 2007, Hilton Head, SC.

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**EDUCATION**

West Virginia University, Morgantown, WV
Major: Mechanical Engineering
Degree: Doctorate of Philosophy, August 2008
Dissertation Chair: Gregory J. Thompson, Ph.D.
Dissertation: The Effects of Fuel Additives on Diesel Engine Emissions during Steady State and Transient Operation

West Virginia University, Morgantown, WV
Major: Mechanical Engineering
Degree: Master of Science, August 2005
Thesis Chair: Gregory J. Thompson, Ph.D.
Thesis: Staten Island Ferry Emissions Reduction

Rochester Institute of Technology, Rochester, NY
Major: Mechanical Engineering
Degree: Bachelor of Science, May 2003

**EMPLOYMENT HISTORY**

**University of North Florida, Mechanical Engineering Program, Jacksonville, FL**
Assistant Professor 8/2011 – present
Teach mechanical engineering courses, acquire project funding, and write proposals, publications and conference papers on research topics.

**West Virginia University, Department of Mechanical and Aerospace Engineering, Morgantown, WV**
Research Adjunct Professor 08/2011 – present
Research heavy-duty vehicle and engine performance and emissions.

**West Virginia University, Department of Mechanical and Aerospace Engineering, Morgantown, WV**
Research Assistant Professor 12/2008 – 7/2011

Research heavy-duty vehicle and engine performance and emissions. Acquire project funding and write proposals, publications and conference papers on research topics.

**West Virginia University, Department of Mechanical and Aerospace Engineering, Morgantown, WV**
Project Coordinator 08/2008 – 10/2008
Research diesel engine emissions, write reports and papers on research topics.

**West Virginia University, Department of Mechanical and Aerospace Engineering, Morgantown, WV**
Graduate Research Assistant 08/2003 – 07/2008
Research diesel engine emissions, write reports, and papers on research topics. Provide support to research programs.

**General Electric - Power Systems, Schenectady, NY**
Controls Engineer, Intern 09/2002 – 11/2002
Research problems, research new ideas, write reports, and update gas turbine controls code and documentation.

**General Electric - Power Systems, Schenectady, NY**
Mechanical Engineer, Intern 03/2002 – 05/2002
Design and research of steam turbine parts in the new product introduction department.

**Laerdal Medical Corporation, Wappingers Falls, NY**
Mechanical Design Engineer, Intern 09/2001 – 11/2001
Conceived innovative products for emergency medicine. Testing and shop experience.

**Gleason Works, Rochester, NY**
CAD Applications Engineer, Intern 03/2001 – 05/2001
Modeled parts and assemblies using Pro-Engineer. Create tutorials and one-on-one help based on Pro-Engineer.

**General Electric - CRD, Schenectady, NY**
Mechanical Engineer, Intern 06/2000 – 11/2000
Responsible for laboratory facility, testing, data acquisition, and preliminary theories based on data.

**ENGINEERING INSTITUTION MEMBERSHIPS**

American Society Of Mechanical Engineers (ASME), Journal and Conference Paper Reviewer

Society of Automotic Engineers (SAE), Journal and Conference Paper Reviewer

**INSTRUCTION**

Fall Semester, 2014, UNF, Thermodynamics I, EML 3100, Enrollment 75.

Fall Semester, 2014, UNF, Introduction to Engineering II, ENG 2009, Enrollment 47.

Spring Semester, 2014, UNF, Thermodynamics II, EML 3101, Enrollment 74.

Spring Semester, 2014, UNF, Internal Combustion Engines, EML 4930, Enrollment 15.

Spring Semester, 2014, UNF, Internal Combustion Engines, EML 6933, Enrollment 4.

Spring Semester, 2014, UNF, Introduction to Engineering II, ENG 2009, Enrollment 35.

Fall Semester, 2013, UNF, Machine Design, EML 4501, Enrollment 50.

Fall Semester, 2013, UNF, Thermodynamics I, EML 3100, Enrollment 64.

Fall Semester, 2013, UNF, Introduction to Engineering II, ENG 2009, Enrollment 47.

Summer Semester, 2013, UNF, Thermodynamics I, EML 3100, Enrollment 48.

Spring Semester, 2013, UNF, Thermodynamics II, EML 3101, Enrollment 57.

Spring Semester, 2013, UNF, Internal Combustion Engines, EML 4930, Enrollment 18.

Spring Semester, 2013, UNF, Internal Combustion Engines, EML 6933, Enrollment 2.

Fall Semester, 2012, UNF, Introduction to Engineering II, ENG 2009, Enrollment 42.

Fall Semester, 2012, UNF, Machine Design, EML 4501, Enrollment 38.

Fall Semester, 2012, UNF, Thermodynamics I, EML 3100, Enrollment 39.

Summer Semester, 2012, UNF, Applied Vehicle Powertrain, EML 4930, Enrollment 15.

Summer Semester, 2012, UNF, Sustainable Engineering Design, CGN 4931, Enrollment 8.

Spring Semester, 2012, UNF, Energy Systems Lab, EML 4004L, Section 1, Enrollment 26.

Spring Semester, 2012, UNF, Energy Systems Lab, EML 4004L, Section 2, Enrollment 26.

Spring Semester, 2012, UNF, Thermodynamics II, EML 3101, Enrollment 37.

Fall Semester, 2011, UNF, Introduction to Engineering II, ENG 2009, Enrollment 75.

Fall Semester, 2011, UNF, Machine Design, EML 4501, Enrollment 60.

Fall Semester, 2011, UNF, Thermodynamics I, EML 3100, Enrollment 41.

Spring Semester, 2011, WVU, Thermodynamics, MAE 320, Enrollment 50.

Fall Semester, 2010, WVU, Thermodynamics, MAE 320, Enrollment 39.

Fall Semester, 2010, WVU, Machine Design and Manufacturing, MAE 454, Enrollment 22.

Fall Semester, 2007, WVU, Machine Design and Manufacturing, MAE 454, Enrollment 27.

**GUEST LECTURES**

"An Experimental Investigation of the Thermal Efficiency, Combustion Process, and Emissions of a Heavy-Duty Diesel Engine Enriched with Hydrogen ($H_2$)," UNF ASME Chapter, February 12, 2013.

"Engine and Powertrain Research," UNF ASME Chapter, January 18, 2013.

"Locomotive Emissions Measurement," Fall Semester, 2010, WVU, Heavy Duty Vehicle Emissions, MAE 525 (Graduate Course), Enrollment 19.

"Chemical Kinetics," Spring Semester, 2010, WVU, Advanced

Thermodynamics 2, MAE 621 (Graduate Course), Enrollment 13.

"In-cylinder Convection Heat Transfer," Spring Semester, 2010, WVU, Advanced Internal Combustion Engines, MAE 593Q (Graduate Course), Enrollment 27.

"In-cylinder Pressure Measurement," Fall Semester, 2009, WVU, Engine Combustion and Emissions, MAE 493H, Enrollment 8.

"The Torque Required for Power Screws," Fall Semester, 2008, WVU, Machine Design and Manufacturing, MAE 454, Enrollment 97.

"Staten Island Ferry Emissions Reduction," Spring Semester, 2007, WVU, Conventional and Hybrid Vehicle Emissions, MAE 593H (Graduate Course), Enrollment 12.

**GRADUATE STUDENT THESIS ADVISOR**

Merritt, Brock MSME (08/11)
"Juxtaposition of In-Use Vehicular Emissions Measurement Equipment"

Morris, Melissa Ph.D. (08/11)
"Development of an Artificial Neural Network to Predict In-Use Engine Emissions"

Kimble, Nathan MSME (08/11)
"Model Based Evaluation of the Differences between Full and Partial Flow Particulate Matter Sampling Systems"

**GRADUATE STUDENT THESIS COMMITTEES**

Ryskamp, Ross Ph.D. (05/14)
"Investigation of High Reactivity Fuel Property Effects on Reactivity Controlled Compression Ignition Combustion"

Olatunji, Idowu MSME (12/10)
"Emissions Characterization and Particle Size Distribution from a DPF-Equipped Diesel Truck Fueled with Biodiesel Blends"

Ryskamp, Ross MSME (12/10)
"Exploration of Injection Strategy and Fuel Property Effects on Advanced Combustion"

Ice, Jason MSME (12/10)
"Investigation of EGR and Fuel Property Effects on Advanced Combustion

Strategies Using In-cylinder Combustion Analyses"

Balakrishnan, Ramamoorthy MSME (08/11)
"Investigation of Particulate Matter Size Distribution and Concentration during Low Temperature Combustion"

**PEER REVIEWED PUBLICATIONS**

**Nuszkowski, J.**, Chvala, J., McCollum, M., and Kinnaly, E., "The Influence of Ambient Wind Conditions on Aerodynamic Friction Energy during On-road Vehicle Operation," Proceedings of the Institution of Mechanical Engineers, Part

D: Journal of Automobile Engineering, (Submitted February 2013).

Li, H., Liu, S., Gatts, T., Liew, C., Wayne, S., **Nuszkowski, J.**, Thompson, G., and Clark, N., "An Investigation of $NO_2$ Emissions from a Heavy-Duty Diesel Engine Fumigated with $H_2$ and Natural Gas," Journal of Combustion Science and Technology, Vol. 184, No. 12, pp. 2008-2035, 2012.

Carder, D., Ryskamp, R., **Nuszkowski, J.**, Li, H., Clark, N., Thompson, G., Gautam, M., and Wayne, S., "Fuels to Enable Light-Duty Diesel Advanced Combustion Regimes," Coordinating Research Council, Inc., August, 2012.

**Nuszkowski, J.**, Flaim, K., and Thompson, G., "The Effect of Cetane Improvers and Biodiesel on Diesel Particulate Matter Size," SAE International Journal of Fuels and Lubricants, Vol. 4, No. 1, pp. 23-33, 2011.

Liew, C., Li, H., **Nuszkowski, J.**, Liu, S., Gatts, T., Atkinson, R., and Clark, N., "An Experimental Investigation of the Combustion Process of a Heavy-Duty Diesel Engine Enriched with $H_2$," International Journal of Hydrogen Energy, Vol. 35, No. 20, pp. 357-365, 2010.

Thompson, G. and **Nuszkowski, J.**, "Neat Fuel Influence on Biodiesel Blend Emissions," International Journal of Engine Research, Vol. 11, No. 1, pp. 61-77, 2010.

**Nuszkowski, J.**, Tincher, R., and Thompson, G., "Evaluation of the NOx Emissions from Heavy Duty Diesel Engines with the Addition of Cetane Improvers," Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, Vol. 223, No. 8, pp. 1049-1060, 2009.

**Nuszkowski, J.**, Thompson, G., and Ursic, M., "The Influence of Accelerator Pedal Position Control during Transient Laboratory Testing on Heavy Duty Diesel Engines," SAE International Journal of Engines, Vol. 2, No. 1, pp. 398-404, 2009.

**Nuszkowski, J.**, Clark, N., Spencer, T., Carder, D., Gautam, M., Balon, T., and Moynihan, P., "Atmospheric Emissions from a Passenger Ferry with Selective Catalytic Reduction," Journal of the Air & Waste Management Association, Vol. 59, No. 1, pp. 18-30, 2009.

**Nuszkowski, J.**, Spencer, T., Clark, N., and Balon, T., "On-board Emissions Measurement and Characterisation of Marine Diesel Engines," Journal of Marine Design and Operations Proceedings of IMarEST - Part B, No. 11, pp. 15-26, 2007.

**PEER REVIEWED CONFERENCE PAPERS/PRESENTATIONS**

Bonsack, P., Ryskamp, R., Besch, M., Carder, D., Gautam, M., and **Nuszkowski, J.**, "Number Concentration and Size Distributions of Nanoparticle Emissions during Low Temperature Combustion using Fuels for Advanced Combustion engines (FACE)," Warrendale, PA, SAE Technical Paper No. 2014-04-01, 2014.

Bonar, H. and **Nuszkowski, J.**, "Gaining "Lost Work" for a Greener Planet," 5th International Conference, Ammonia Refrigeration Technology (Ohrid, Republic of Macedonia), May 9-11, 2013.

Littera, D., Bonsack, P., Ryskamp, R., Besch, M., Carder, D., **Nuszkowski, J.**, and Gautam, M., "Concentration and Size Distributions of Nanoparticle Emissions during Low Temperature Combustion using Fuels for Advanced Combustion Engines," 16th ETH Conference on Combustion Generated Nanoparticles (Zurich, Switzerland), June 24-27, 2012.

Ryskamp, R., **Nuszkowski, J.**, Carder, D., Bonsack, P., and Gautam, M., "Comprehensive Investigation of Fuel Property Effects on Light-Duty Compression Ignition Advanced Combustion" 22nd CRC On-Road Vehicle Emissions Workshop (San Diego, California), 2012.
**Nuszkowski, J.**, Flaim, K., and Thompson, G., "The Effect of Cetane Improvers and Biodiesel on Diesel Particulate Matter Size," Warrendale, PA, SAE Technical Paper No. 2011-01-0330, 2011.

Dam, M., **Nuszkowski, J.**, and Thompson, G., "Experimental Investigation into the Effects of Oil Aging on Laboratory Measurement of Emissions from a Heavy-duty Diesel Engine," Warrendale, PA, SAE Technical Paper No. 2011-01-1163, 2011.

Clark, N., McKain, D., Sindler, P., Jarrett, R., **Nuszkowski, J.**, Gautam, M., Wayne, S., Thompson, G., and Sonny, R., "Comparative Emissions from Diesel and Biodiesel Fueled Buses from 2002 to 2008 Model Years," Warrendale, PA, SAE Technical Paper No. 2010-01-1967, 2010.

Olatunji, I., Clark, N., Sindler, P., McKain, D., Thompson, G., Gautam, M.,

Wayne, S., and **Nuszkowski, J.**, "Biodiesel Blend Emissions of a 2007 Medium Heavy Duty Diesel Truck," Warrendale, PA, SAE Technical Paper No. 2010-01-1968, 2010.

**Nuszkowski, J.** and Thompson, G., "Biodiesel Blend NOx Emissions from Heavy Duty Diesel Engines," 2nd International Congress on Biodiesel: The Science and The Technologies, Munich, Germany, November, 2009.

**Nuszkowski, J.** and Thompson, G., "The Influence of Accelerator Pedal Position Control during Transient Laboratory Testing on Heavy Duty Diesel Engines," Warrendale, PA, SAE Technical Paper No. 2009-01-0619, 2009.

**Nuszkowski, J.** and Thompson, G., "Application and Repeatability of Transient Heat Release Analysis for Heavy Duty Diesel Engines," Warrendale, PA, SAE Technical Paper No. 2009-01-1125, 2009.

**Nuszkowski, J.**, Thompson, G., Tincher, R., and Clark, N., "Heat Release and Emission Characteristics of B20 Biodiesel Fuels During Steady State and Transient Operation," Warrendale, PA, SAE Technical Paper No. 2008-01-1377, 2008.

**Nuszkowski, J.**, Bolyard, J., Thompson, G., and Carder, D., "In-Use Heavy-Duty Diesel Emissions Measurement Using An Air-to-Fuel Ratio Derived Exhaust Flow Rate," Proceedings of ICEF2007 ASME Internal Combustion Engine Division 2007 Fall Technical Conference, ASME Paper No. ICEF2007-1780, Charleston, SC, 2007.

**Nuszkowski, J.**, Thompson, G., and Clark, N., "Experimental and Error Analysis Investigation into Dilution Factor Equations," Warrendale, PA, SAE Technical Paper No. 2007-01-0310, 2007.

**Nuszkowski, J.**, Thompson, G., Chiaramonte, M., Hu, J., and Moles, N., "Pressure Drop and Cleaning of In-Use Ash Loaded Diesel Particulate Filters," Warrendale, PA, SAE Technical Paper No. 2006-01-3256, 2006. (Included in the book, Johnson, T.V., "Diesel Particulate Filter Technology", SAE, Toronto, CA, 2007).

**CONFERENCE POSTERS**

**Nuszkowski, J.**, Olatunji, I., Clark, N., Werner, T., and McLaughlin, S., "Predicting and Utilizing the Vehicle's Past and Future Road Grade," Directions in Engine-Efficiency and Emissions Research Conference (Detroit, Michigan), October 2011.

Ice, J., Ryskamp, R., Balakrishnan, R., **Nuszkowski, J.**, and Shade, B., "In-cylinder

Combustion Techniques to Identify Advanced Combustion," 21th CRC On-Road Vehicle Emissions Workshop (San Diego, California), 2011.

Ryskamp, R., Ice, J., Balakrishnan, R., **Nuszkowski, J.**, and Shade, B., "Characterization of Fuels to Enable Advanced Combustion in a Light Duty Compression Ignition Engine Through Emissions and Performance Measurements," 21th CRC On-Road Vehicle Emissions Workshop (San Diego, California), 2011.

Shade, B., **Nuszkowski, J.**, Thompson, G., Wayne, S., Gautam, M., and Clark, N., "Regulated Emissions of Heavy-Duty Diesel Engines - Past, Present and Future," Proceedings of the Better Air Quality (BAQ) 2010, Singapore, November 2010.

**Nuszkowski, J.**, Shade, B., "The Impact of using Derived Fuel Consumption Maps to Predict Fuel Consumption," Directions in Engine-Efficiency and Emissions Research Conference (Detroit, Michigan), September 2010.

Shade, B., **Nuszkowski, J.**, Thompson, G., Wayne, S., Gautam, M., Clark, N., and, Atkinson, C., "Regulated Emissions of Heavy-Duty Diesel Engines - Past, Present and Future," 20th CRC On-Road Vehicle Emissions Workshop (San Diego, California), 2010.

Carder, D., **Nuszkowski, J.**, Shade, B., Thompson, G., Clark, N., and Gautam, M., "Development and Demonstration of a Next Generation Mobile Heavy-Duty Emissions Testing Laboratory," 20th CRC On-Road Vehicle Emissions Workshop (San Diego, California), 2010.

Carder, D., Wu, Y., **Nuszkowski, J.**, Shade, B., Clark, N., and Gautam, M., "Development of a Transportable, 1065-Compliant Emissions Measurement System," Directions in Engine-Efficiency and Emissions Research Conference (Dearborn, Michigan), 2009.

Shade, B., **Nuszkowski, J.**, Thompson, G., and Clark, N., "Statistical Analysis of Transient Cycle Test Results in a 40 CFR Part 1065 Engine Dynamometer Test Cell," Directions in Engine-Efficiency and Emissions Research Conference (Dearborn, Michigan), 2009.

Liew, C.M., Li, H., Gatts, T., **Nuszkowski, J.**, Xu, S., Rapp, B., and Clark, N., "An Investigation of Combustion and Emissions Characteristics of Heavy-Duty Diesel Engines Supplemented with Hydrogen," Directions in Engine-Efficiency and Emissions Research Conference (Dearborn, Michigan), 2009.

**PROJECTS**

"Design and Construction of a Fluid Amplifier Cooler," Bonar Engineering, Inc., Jacksonville, FL, June 2014 – June 2015, $25,000.

"Energy Efficient Vehicles," UNF Foundation Board, Jacksonville, FL, January 2014 – December 2014, $15,000.

"Small Scale Engine Performance Screening for Alternative Navy Fuels," Principle Investigator, West Viriginia University, Morgantown, WV, January 2013 – December 2013, $6,000.

"Assessment of "the Expander," an Apparatus and Method for converting Thermal to Electrical Energy," Henry B. Bonar II, Jacksonville, FL, November 2011 – August 2012, $10,176.

"Support for the Fuels to Enable Light-Duty Diesel Advanced Combustion Regimes Project," Principle Investigator , West Viriginia University,

Morgantown, WV, August 2011 – March 2012, $22,000.

"Fuels to Enable Light-Duty Diesel Advanced Combustion Regimes," Principle Investigator as of 12/30/2010, Coordinating Research Council, Inc., Dec. 1, 2008 – Nov. 30, 2011, Alpharetta, GA, $434,514.

"Norfolk Southern Tier 0 Emissions Evaluation," Co-Investigator, Norfolk Southern Railway Company, Nov. 1, 2010 – July. 31, 2010, Roanoke, VA, $166,452.

"Regulated Gaseous and PM Emissions of In-use Heavy-Duty Trucks," Principle Investigator as of 12/29/2010, Caterpillar, Inc., Oct. 1, 2009 – Jun. 30, 2011, Mossville, IL, $159,626.
"Norfolk Southern Tier 0 Emissions Evaluation," Co-Investigator, Norfolk Southern Railway Company, Aug. 1, 2010 – Dec. 31, 2010, Roanoke, VA, $131,798.

"Norfolk Southern Tier 0 Emissions Evaluation," Co-Investigator, Norfolk Southern Railway Company, Mar. 1, 2010 – Dec. 31, 2010, Roanoke, VA, $166,452.

"CARB Verification of Süd-Chemie / Diesel Emission Technologies PDPF," Co-Investigator, Süd-Chemie, Inc., June 1, 2009 – Dec. 31, 2010, Needham, MA, $83,460.

"TCEQ Certification of a Fuel Additive," Co-Investigator, Afton Chemical Corporation, Dec. 1, 2009 – Dec. 31, 2010, Richmond, VA, $98,823.

"Rypos Level 3 Plus TRU Verification Using the CARB Procedure," Principle Investigator as of 12/29/2010, Rypos, Inc., Jun. 30, 2011 – Dec. 31, 2010, Holliston, MA, $68,909.

"Norfolk Southern Tier 0 Emissions Evaluation," Co-Investigator, Norfolk Southern Railway Company, Aug. 1, 2009 – Dec. 31, 2010, Roanoke, VA, $92,747.

"Regulated Gaseous and PM Emissions of In-use Heavy-Duty Trucks," Principle Investigator as of 12/29/2010, Caterpillar, Inc., Dec. 1, 2009 – Jun. 30, 2011, Mossville, IL, $300,000.

"Biodiesel Fleet Emissions and Greenhouse Gas Demonstration," Co-Investigator, Central Florida Regional Transportation Authority (LYNX), Oct. 1, 2009 – Mar. 31, 2010, Orlando, FL, $488,513.

"Engine Dynamometer Researh for an Air Moving Device," Co-Investigator, Global Sus. Technologies, Oct. 1, 2009 – Dec. 31, 2009, Knoxville, TN, $46,889.

"Refined Fuel Additive Effects on Emissions," Principle Investigator, Afton Chemical Corporation, Sep. 1, 2009 - June 30, 2010, Richmond, VA, $16,466.

"Verification of 40 CFR Part 92 Compliance Testing for Auxiliary Engines," Principle Investigator, Emisstar, Aug. 1, 2009 – Dec. 31, 2009, New Boston, NH, $9,282.

"Norfolk Southern Tier 0 Emissions Evaluation," Co-Investigator, Norfolk Southern Railway Company, Aug. 1, 2009 – Dec. 31, 2009, Roanoke, VA, $156,722.

"Evaluation of Production Heavy-Duty Diesel Engines for 2010 Emissions Compliance," Co-Investigator, Mack Trucks, Inc., July 1, 2009 – Dec. 31, 2009, Hagerstown, MD, $88,190.

"Fuel Additive Effects on Emissions," Co-Investigator, Afton Chemical Corporation, May 1, 2009 – Apr. 30, 2010, Richmond, VA, $16,400.

"Advanced Powertrain Simulation," Principle Investigator, Mack Trucks, May 1, 2009 – Jan. 31, 2010, Hagerstown, MD, $50,641.

**DEPARTMENT, COLLEGE, UNIVERSITY SERVICE**

1. SoE Guidelines Committee, Department Service, UNF, Spring 2014.
2. Graduate Program Review Committee, Department Service, UNF, Fall 2013 - Spring 2014.
3. ME Search Committee, Department Service, UNF, Fall 2013 - Spring 2014.
4. Engineering Scholarship Committee, Department Service, UNF, Fall 2013 - Spring 2014.
5. Design Report Committee, Department Service, UNF, Spring 2013.
6. Outstanding Undergraduate Teaching Award Committee (Chair), College Service, UNF, Spring 2013.
7. Outstanding Graduate Teaching Award Committee, College Service, UNF, Spring 2013.
8. Critical Thinking Committee Member, Department Service, UNF, Fall 2011 – Spring 2013.
9. Outstanding Undergraduate Teaching Award Committee, College Service, UNF, Spring 2012.
10. Critical Thinking Committee Member, Department Service, UNF, Fall 2011 – Spring 2012.
11. Faculty Retention Committee Member, University Service, WVU, Spring – Fall 2010.

**SYNERGISTIC ACTIVITIES**

- Evaluation and development of novel thermodynamic systems
- Evaluating fuels for advanced combustion

- Investigating complete powertrain strategies that decrease fuel consumption.
- Development and evaluation of a new raw emissions laboratory for testing locomotives and marine vessels.
- Evaluation of a new chassis emissions laboratory for testing vehicles year 2007 or newer.
- Evaluation of biodiesel fuels and diesel fuel additives using in-cylinder pressure measurement during steady state and transient testing.
- Development of combustion models based on the measurement of in-cylinder pressure for diesel engines under steady state and transient operation.
- Measurement of gaseous and particulate emissions from heavy-duty on-road and off-road vehicles and equipment for atmospheric pollutant inventory modeling and prediction.
- Development and evaluation of advanced exhaust aftertreatment systems such as catalyzed particulate filters, selective catalytic reduction (SCR), and oxidation catalyst systems for diesel engines.

# APPENDIX B

# CHARGE TO REVIEWERS

# PEER REVIEW CHARGE

**DTNH22-13-D-00298 – Task Order 0003, Report 1**
**December 2014**

***"Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #1"***

## BACKGROUND

In September 2012, NHTSA competitively awarded a contract to Southwest Research Institute (SwRI) to conduct research in support of the next phase of Federal fuel efficiency (FE) and greenhouse gas (GHG) standards. Tasks included determining the baseline fuel efficiency and emissions levels and technologies of current model year commercial medium- and heavy-duty on-highway vehicles and work trucks, as well as projections of Phase 2 (post-2018 model year) fuel efficiency and emission reduction technologies. The scope encompassed technologies for chassis and final-stage manufacturer vehicles and trailers, maintenance cost, material application, future design, electric and hybrid propulsion systems, capital investment, retail cost/payback and any other applicable advanced technologies. Estimates of the costs, fuel savings effectiveness, availability, and applicability of technologies were done for each individual vehicle class category (e.g., segment).

The resulting report series (herein referred to as the SwRI MD/HD Technology Effectiveness and Cost Reports) consists of three sequential reports. All three reports are from the same project, and involve the same technologies, engines, and vehicles; however, due to their large size, they have been separated into three documents to facilitate review and publication. This review covers the first of these reports. The first report contains an assessment of the current commercial fleet technology baseline at the time of contract award (MY 2011/2012) and an assessment of effectiveness and cost of potential fuel efficiency/GHG-improving technologies.

## REPORT #1 OVERVIEW

Report # 1 was divided into three tasks:

The **first task** consisted of a literature survey covering:

- Fuel saving technologies for MD/HD engines and vehicles.
- Market segmentation of fleets.
- Current and planned MD/HD fuel economy regulations in markets around the world.

Based on the results of this review, NHTSA, EPA and SwRI agreed on a list of vehicle and engine technologies that form the main subject of this project. The results of the first task are presented in Section 2 of this report.

The **second task** was an analysis of the range of fuel efficiency and GHG reduction performance for technologies that were selected at the end of the literature review. SwRI used the SwRI Vehicle Simulator

tool, a vehicle simulation tool developed in-house, to model vehicle performance over a range of drive cycles. A range of vehicle models was created to cover the range of Class 2b through Class 8b. Vocational truck applications were emphasized, since less information is available on the performance of these vehicles as compared to larger segments such as long haul. The commercial software GT-POWER (Gamma Technologies, Inc.) was used to model engine performance, fuel consumption, and $CO_2$ emissions over the full speed-load range. A range of two gasoline and two diesel engines were simulated, with additional permutations to cover gaps in the engine size range. Since GT-POWER is not an appropriate tool for evaluating other greenhouse gas emissions, such as $N_2O$ or $CH_4$, these were not addressed by the project. This second task also included an evaluation of the impact of NOx emissions standards on engine fuel consumption. The results of the second task are covered in Section 3 of this report.

The **third task** included a review of (1) fuel efficiency metrics that take vehicle work and use into account, (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.), and (3) efficiency simulation approaches. The third task is covered in Section 4 of the report.

**Appendix A** provides details of each gasoline engine model, including sources of input data and comparisons to experimental results; describes the assumptions made for each technology; and includes the fuel map results for each gasoline engine and technology. **Appendix B** includes the same information for the two diesel engines. **Appendix C** describes the vehicle simulation and vehicle technologies, and **Appendix D** describes the bottoming cycle model.

## CHARGE QUESTIONS

In your written comments, please provide a detailed response to all of the following questions that are within your area of expertise. Reviewers will be expected to identify additional topics or depart from these examples as necessary to best apply their particular area(s) of expertise. Comments shall be sufficiently clear and detailed to allow readers to thoroughly understand their relevance to this study. **Additional supporting data files, engine maps/models, images, and materials may also be provided to reviewers upon request.**

### 1. Literature Review

1-1. Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included this section and explain why they would be helpful.

1-2. Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b? Are the selected technologies suitable as the basis for the analysis?

### 2. Performance Analysis of Technologies

2-1. Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?

2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?
2-3. Are the assumptions used in the analysis reasonable? Why or why not?
2-4. Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.

**3. Evaluation of Testing and Simulation Approaches**

3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.

**4. General Comments**

4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.
4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?
4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?
4-4. Please provide any other comments you may have on this report.

**5. Overall Recommendation**

5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

# APPENDIX C

# INDIVIDUAL REVIEWER COMMENTS

**COMMENTS SUBMITTED BY**

Matthew J. Barth, Ph.D.
Jacques and Eugene Yeager Families Endowed Chair; and
Professor of Electrical Engineering
Director, Center for Environmental Research and Technology
College of Engineering
University of California
Riverside, California

**PEER REVIEW OF DTNH22-13-D-00298 – Task Order 0003, Report 1**

***"Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #1"***
**December 2014**

## 1. Literature Review

**1-1. Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included this section and explain why they would be helpful.**

- Overall, the literature review provided in the report seems fairly complete. A few comments are provided below.
- The engine and vehicle fuel savings technology ((1) listed above) seems fairly complete, with some commentary below:
  - Section 2.3.1.4: nicely written, I wonder if there are some references that show how downsizing and turbocharging benefits vary across different driving cycles.
  - Section 2.3.1.5: misspelling of 2025 (20205)
  - Section 2.3.1.6: idle reduction is now a hot topic, particularly in the light duty "start-stop technology" arena. I wonder if additional references beyond the single truck reference can be provided;
  - Section 2.3.3: shouldn't there be a section on lean-burn control technology, and the trade off with NOx emissions? Maybe this is in a different section. This could also be highlighted in Section 2.3.4.
  - Is the paragraph in section 2.3.5 on engine downspeeding in the right place?
  - In section 2.3.5.2: any mention of potential fuel economy improvements?
  - In section 2.4.2.2, there are now some more recent truck aerodynamic studies, sponsored by CARB, being conducted by NREL and UCR CE-CERT. It would be good to reference these.
  - Section 2.4.2.3: similarly, there has been a significant amount of new research results on hybrid drivetrains since 2012; visiting the DOE Vehicle Technology Research website cites many of these new studies.
- The approach and references for market segmentation ((2) listed above) seem appropriate, using the most up-to-date sources. This reviewer does not know of any other sources that may be better.

- For the worldwide fuel efficiency regulations ((3) listed above), I wonder if the report can comment more on the potential "good practices" and "bad practices" of the other methods used in different parts of the world. For example, the approach used by China using a single driving cycle seems somewhat limited in the results they can produce. Also, the Japanese top runner program focuses on engine efficiency, not vehicle efficiency (as the report states); however, I believe Japan's JCAP and related programs (see, e.g., http://www.pecj.or.jp/english/jcap/ jcap1/index_jcap1.html) have done more extensive vehicle fuel economy testing.

- Strangely missing from the worldwide fuel regulation literature is what the European Commission is doing… This should be included in the report.

- Section 2.2.3 primarily only discusses the fuel efficiency test and analysis methodology used in this report; some additional language should be provided on other methods, including a big emphasis on using vehicle activity data sets rather than just using "representative" driving cycles.

**1-2. Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b? Are the selected technologies suitable as the basis for the analysis?**

It seems this question can be answered better from section 3 of the report, not the literature review. In any case, here are the comments:

- Overall, the engines selected for performance analysis seem appropriate. The reason given for the selection is that they are the "most popular engine" in the medium duty class 7 trucks and the low end of class 8. For the larger engine, the selection was again made because the engine is "popular". I believe this is true and don't contest this, however it would be useful to have some kind of table or graph that shows the relative population of the different engine technologies in these vehicle classes (from CALHEAT or from POLK data?).

- On page 25, 3rd paragraph, it is stated that some engine sizes had to be modeled based on recalibrating the GT model for a larger size engine and a smaller size engine. It is unclear how this was done. What parameters were modified in the GT model to do this? How were the results (partially) validated?

- Similarly, the selection of the representative gasoline engines seems appropriate based on what is most popular. Same statements as above apply.

- As for the engine technologies selected for performance analysis, in general the selection seems comprehensive given the description of the technology in Section 2. However, it isn't stated anywhere in the report on how the different engine technologies (and combinations) were selected for analysis. Was there a scientific method, such as principal components analysis on the potential benefits of the individual technologies and their combinations? That could be a starting point, and then the list could be pared down based on technical realism. I think the list is fairly complete, but I suggest a paragraph be added on how the different engine technologies were selected for analysis.

- As for the vehicle technologies selected for performance analysis, again in general the selection seems comprehensive given the description of the technology in Section 2. But again, it isn't stated anywhere in the report on how the different engine technologies (and combinations) were selected for analysis. Was there a scientific method, such as principal components analysis on the potential benefits of the individual technologies and their combinations? That could be a starting point, and then the list could be pared down based on technical realism. I think the list is fairly complete, but I suggest a paragraph be added on how the different vehicle technologies were selected for analysis.

**2. Performance Analysis of Technologies**

**2-1. Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?**

The methodology used for performance analysis of the various engine and vehicle technologies evaluated in this report were of good quality and were sufficiently comprehensive to provide valuable results. There are specific comments about how the method handles transients and other issues in the comments below, but overall I am satisfied with the overall evaluation methodology. The results are meaningful and allow for sufficient comparison between the different technologies.

**2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?**

- Regarding GT-Power, I believe that this is an appropriate model to simulate engine fuel efficiency. All of the reasons for using a 1-D CFD model like GT-Power are given on page 33 (all of the bullet items), but it would certain be good to have some key references here that back up the various statements. I'm sure that there are some SAE papers and other papers that talk about advantages and disadvantages of engine models and have validation data to back it up, comparing real-world experimental data to modeled data. For example, it is stated that GT-Power gives "fairly accurate representation of overall fuel consumption and CO2 emissions, typically within +-3%". Where is the reference paper that shows that? One or more reference would give this a lot more credibility.

- As a step in between engine and vehicle modeling, speed – load tables are created for 20x20 operating points. It is assumed that all of these points were simulated at steady-state conditions, not transient conditions, correct? I think several of the engine and vehicle technologies being considered in this report might have significant performance differences depending on how the operating points were entered (i.e., from what previous operating point). This is sometimes referred to as a *history* effect; this may not be very significant with fuel consumption performance, but it can certainly have a major effect with pollutant emissions. Can the authors comment on this?

- Regarding driving cycles, there is some reasoning provided in the report that describes why these certain cycles were selected, providing a good range of operations for the different vehicle types. However the reasoning doesn't seem very rigorous. A far better approach would be to examine

*vehicle activity data* (i.e., real world trajectory data from subsets of these vehicles) from the vehicles in question, and then select and compare driving cycles that are representative of the vehicle activity data itself. The number of publically-accessible vehicle activity data sets is increasing rapidly and should be utilized if at all possible (e.g., NREL's activity database described at http://www.nrel.gov/transportation). Better yet, rather than use driving cycles at all, why not run entire vehicle activity datasets (appropriate for the vehicle technology) directly through the model(s)? The computational time of these models is not that severe, so processing all of these data should not take too much time. That way you skip any controversy regarding whether the driving cycles are representative or not.

- Overall, I think the modeling methodology using the SwRI Vehicle Simulator tool is sufficient for this study. However, it would be good to have perhaps as a separate appendix that provides a validation run showing how well the model does for a few example cases. You could take a vehicle, measure it on a dynamometer, then compare the resulting data with the modeled data for the same driving cycle. Through regression plots, you could determine any model bias and model uncertainty. Showing one example of this would give the reader confidence on how well the SwRI Vehicle Simulator tool performs.

- Very minor question: are either the SwRI vehicle simulator tool or the GT-Power model stochastic in any way? Is there any "randomness" that is used as one of the operating variables? This is often done with transportation models to evaluate the true randomness of traffic and to understand different degrees of uncertainty. I assume that there aren't any strong variables that are random in the case of the engines or vehicles and that both of the models used here were strictly deterministic and ran only once per evaluation scenario.

**2-3. Are the assumptions used in the analysis reasonable? Why or why not?**

Yes, the assumptions seem reasonable, based on my own modeling experience. However, to test whether many of the assumptions are valid, you could certainly do the validation testing described above.

**2-4. Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.**

In general, the findings and conclusions are adequately supported by the simulation results. Some general comments are as follows:

- The commentary about the variable valve lift technology for this diesel engine at the bottom of page 38 seems strange. If a few operating points were analyzed and used to determine that the technology doesn't perform that well, how do you know that the technology doesn't perform better at other operating points? This either needs better explanation, or the full analysis should be completed. Just because the savings are small isn't a good reason to exclude it; other technologies in table 3.13 show small savings of 0.1% (e.g., technologies 10 and 11).

- For completeness, it would be good to repeat figure 3.4 for not just 50% payload, but also for the other payload set points.

- Section 3.3.1.14, it isn't clear what is meant by stating "making OBD very challenging", I think the authors mean that the emissions control system design for aftertreatment is very challenging, right?
- For technologies 17 and 18 (sections 3.3.1.17 and .18), it would be good to illustrate the results here for the different payloads. It seems very logical to downsize an engine, but then realize that the performance of the vehicle drops off (e.g., acceleration rates, etc.). With the lower acceleration rates, was the vehicle model able to keep up with the target speeds of the driving cycle? Were there some of the configurations (e.g., large engine downsizing, high payload, aggressive cycle) where the vehicle could not "follow" the driving cycle? If so, how did you carry out the simulation? Was the drive cycle simply extended, or was it cut short? This has a large implication on what the final fuel consumption reductions would be.
- Similar to figure 3.4, it would be good to repeat figure 3.5 for not just 50% payload, but also for the other payload values. This is particularly true where later in the report it is stated: "fuel savings offered by most vehicle technologies is very duty cycle and payload dependent".
- For section 3.3.2.4, the weight issue makes perfect sense. However, won't truck operators in many cases increase their payload to max out their weight for economic reasons, thereby negating any weight loss gains?
- For the speed governors, this was only evaluated for a single cycle that obviously had vehicle target speeds above the speed governor set points (55mph and 60 mph). It is not clear how the cycles were actually applied in the simulation runs when the simulator could not hit the "target" speeds of the cycle. Was the rest of the cycle played out to the end, or was the cycle truncated? Was the cycle completed on a time basis or on a distance basis? Based on the discussions of the longer trip times, I assume the cycle was played out until the end. These are very important issues in terms of determining the final fuel savings. In the real world, the trip still needs to be complete, so the evaluation should be completed on a distance basis, and the overall fuel economy should be calculated for the entire trip. The authors point this out to some degree, but this could use some more explanation.
- It would be good to repeat figures 3.13, 3.14, and 3.15 for not just 50% payload, but also for the other payload values. We want to see sensitivity analysis based on payload differences. If there are very little differences, then state so.
- In section 3.3.3.18, when the downsized engines were run for the more aggressive cycles with grade, the vehicles cannot follow the cycles; similar to previous questions, how did you handle the remaining part of the cycle in the evaluation run? It makes a big difference in the results.
- In section 3.3.3.20, it is stated that the technology is only applied to certain cycles that long steady-state components, since the response to other cycles is minimal. But why not run the evaluations for these other cycles, just to show that the technology is not effective? How was the transient response handled when the modeling approach is essentially "steady-state" in nature? Were there time constants and other thermal parameters involved? I think the modeling approach on this technology needs a bit more explanation.

- For section 3.3.3.21, same comments/questions as above.
- For section 3.3.2.1, is the AC cycled? Or is it assumed to be a constant load throughout the cycle in question? In the real-world, the AC compressor will cycle depending on temperature and humidity involved. I'm not sure if this will make much of a difference in the results.
- The authors mention the tradeoffs between weight reductions, and increases in weight with possible increased payload. This is certainly true that carriers will try to maximize the economics of moving goods, so any down-weighting will likely be replaced with increased payload weight.
- For table 3.24, for the cycles that weren't able to complete, see previous comments/questions about how were the simulations completed in those cases.
- I like the discussion of section 3.4 on the fuel economy and NOx and PM tradeoffs. This will always be an important issue as the NOx and PM standards get progressively more severe. In the analysis, I didn't see any mention of specific future NOx and PM emission standards with specific numbers. Why not use those more restrictive numbers in this analysis, especially when looking at future fuel economy standards? I think the text discusses this in general, but I didn't see the specific numbers.

**3. Evaluation of Testing and Simulation Approaches**

**3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.**

Section 4 is well written and touches on all the key issues. I believe it adequately addresses and summarizes the different fuel efficiency metrics and engine efficiency test procedures. Some specific comments:

- It is stated that "A dynamometer test on an appropriate duty cycle is a more reliable way to determine efficiency". In line with some of the earlier comments about modeling methodology, there is now a big push to get away from duty cycles (because of the issues of whether they are always appropriate) and to do more in-use measurements in the real-world. We have the technology to measure overall performance and to aggregate the performance data and record and evaluate it (overall, this falls into a "Big Data" scenario). So why not put the engine and technology in place, measure the performance for a wide range of uses, and then use those numbers to set new standards in subsequent years? The details of this needs to be fleshed out, but the trend is to get away from dynamometer testing. The middle paragraph on page 101 touches on this a bit.
- On page 97, it is stated that "we recommend that it be left to manufacturers to develop approaches for validating the performance of fuel saving technologies that fall into this realm". I would be a bit wary about letting the manufacturers do the validation, the nature of the

manufacturers is to maximize economics and that sometimes that gets in the way of proper testing.

- The discussion on hybrid technologies is another wrinkle in the evaluation methodology, I assume this will be addressed more fully in subsequent reports. But this just goes to show you that an in-use evaluation approach mentioned above will also work well with hybrid technology.
- On page 99, "Driver reward systems" are part of the eco-driving techniques mentioned in the general comments below, which should be considered, but seem to fall outside the scope of this analysis.
- On page 100, it is mentioned that OEMs have very sophisticated tools that are routinely used to optimize specifications for customer applications; why not optimize these parameters in real-time based on vehicle performance, to the extent possible? I wonder if some discussion can be made on these "learning" techniques that can be applied to engine and vehicle operation.
- Overall, there is very good coverage on the international standards work, in many ways, this covers the comments I made earlier.
- I like the discussion on the payload sensitivity, and the drive cycle sensitivity. This section addresses in part some of the comments and questions made above.

## 4. General Comments

### 4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

- Overall, the report is well written and organized. The order of the literature review cited in this review charge is slightly different than how it is presented in the actual report, but that is only a minor issue.
- One key thing that would be helpful in the introduction is some better scoping sentences. Fuel economy is affected by a number of different things, generally categorized into four areas: 1) vehicle technology effects; 2) vehicle fuel effects; 3) driver behavior effects; and 4) roadway infrastructure effects. Obviously this report deals with the area of 1), i.e., what kind of on-board vehicle technology exists that can improve fuel economy. Even though it is out of the scope of the report, different fuels and fuel additives have an effect on fuel economy, there is significant research and products in this area. Regarding 3), there is now technology that affects how a driver operates the vehicle. Example of this technology include eco-driving aids and real-time navigational aids showing roadway status (e.g., upcoming grade, traffic, etc.). In a sense, this driver feedback technology changes the "driving cycle" that is applied to the vehicle in a typical testing environment. When employed, this eco-driving feedback technology allows for different levels of fuel economy savings, see DOE vehicle technology program references (e.g., see http://energy.gov/sites/prod/files/2014/07/f17/vss087_verma_2014_o.pdf and http://energy.gov/sites/prod/files/2014/12/f19/2014_amr.pdf). Again, this should at least be mentioned in the introduction or literature review, but should probably not be included in the

current analysis. Regarding 4), there are roadway infrastructure and traffic operation techniques that can also affect vehicle fuel economy. These include things like traffic signal synchronization, variable speed limit techniques on freeways, adaptive ramp metering, etc. Although this is not vehicle technology per se, this roadway technology can improve overall traffic fuel economy. Again, this is outside the scope of this report, but perhaps it should still be mentioned in the introduction.

- The NOx reducing technology "LNT" needs to be defined in the report. It is referenced but never explained.
- The report seems to end rather abruptly. Is there or should there be a conclusions section?

**4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?**

Overall the information provided in the report is sufficiently detailed; various comments on specifics have been provided above.

**4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?**

The strongest part of the report was section 4, in terms of the analysis and comparison of the technologies, and the methodology comparison. The weakest part of the report was the lack of specific figures in the detailed analysis section. The weakest parts of the report can be improved by addressing some of the comments made above, and including some of the figures suggested in the text above.

**4-4. Please provide any other comments you may have on this report.**

Overall, good report and appendices.

**5. Overall Recommendation**

**5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.**

Based on my review, the report and appendices are acceptable with minor revisions. There are a variety of comments and suggestions made in the above text that the authors could address.

**COMMENTS SUBMITTED BY**

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# PEER REVIEW CHARGE

**DTNH22-13-D-00298 – Task Order 0003, Report 1**

**December 2014**

***"Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #1"***

## 1. Literature Review

**1.1 Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included this section and explain why they would be helpful.**

*1. Addressing key data sources of fuel saving technologies for MD/HD engines and vehicles.*

The **Engine Technologies** section (2.3) provides a brief overview of major technologies that have risen in the last years and have made their way into the LD and HD markets. The treatment is consistent: the report is brief, highlights one or two significant points, and makes one to three references for each category.

The approach is adequate given the very extensive literature available. This section may be improved by indicating the relative success or the acceptance of these technologies onto OEM products.

This first part of this section focuses on spark ignition engines before transitioning to Diesel. Under the gasoline category, other systems could be included. A few suggestions are given here for more completeness: VVA, Atkinson cycle, Miller cycle (addressed in part on *2.3.1.4*).

The **Vehicle Technologies** section (2.4) is also very concise across the technologies reviewed, with few representative references quoted. Review of these references fail to give any useful information to the reader. Some examples are given below.

- On page 15. The authors can give more detail as to what technologies are considered. *"In a study by Saricks… various technologies is considered [VT-10]. A base case, in which innovation proceeds at its current pace, and an accelerated implementation pace, are considered… Both engine and vehicle technologies are considered."*

- On page 15. The authors discuss the type of study rather than provide a useful summary to the reader. *"A particular medium duty vehicle was evaluated in an Argonne study [VT-13]. Technologies including aerodynamic drag reduction, rolling resistance reduction, transmission improvements, and vehicle weight reduction were applied to a baseline vehicle. Each technology* was considered individually, and then various technology groupings were studied."

*2. Addressing key data sources of market segmentation of fleets.*

This appears to be the area addressed in Specific Requirement (SR 3), which according to the stamen on top of page 3, was not completed. Only brief references to market segmentations are given in the text.

The report would have gained a lot from the documented performance and fuel consumption on a wider range of products. As this effort continues, this may be manageable by contacting a number of well known fleets that track very carefully these benchmarks. The information would complement the more detail data made available from the chosen platforms.

*3. Addressing current and planned MD/HD fuel economy regs in markets around the world.*

This reviewer finds the review of fuel economy regulations very weak.

In section 2.2.1, pertaining North American Fuel Economy regulations, further discussion is needed on EPA/NHTSA Phase 1 regulations (page iii, 1, 5). This being such a significant grounding point for the work undertaken, rather than limiting to a reference to the EPA website, the present report should describe and outline here the 1st and second stages. Specifically:

a. Insert a tabular representation the GHG targets.

b. Indicate how did OEM companies comply with GHG targets.

c. Show GHG standards with industry average, high and low market entries.

d. Tabulate GHG emissions for these engines vs. technologies that are being carried.

In Section 2.2.2 Worldwide FE regulations, Chinese and Japanese regulations are discussed. A summary with CO2 g/bhp-hr benchmarks should be included as noted in the earlier North American section and inserted in tabular form. Insert references.

Euro regulations are not covered here and should be included as well. Insert reference.

**Other Observations:**

The report could be enhanced (specially the review section) by highlighting what technologies have the major OEMs adopted and their relative fuel improvements towards the 2014 and 2017 GHG targets.

**Corrections and Typos:**

- Page 7 insert “of refeference [R-7]“ in sentence *Pages 23 through 28 “of reference [R-7]” discuss* …
- Page 9: “viable in the 201~~0~~5 time frame”
- Page 9: “de ~~Ojeta~~ [Ojeda] reports”
- Finish sentence on page 9: “eclectic power, ~~then~~ [whereupon it is] re-condensed [prior to pumping it again into the boiler unit].”

- Sentence on page 12 mixes EGR /air handling aspects with aftertreatment. Should be deleted or corrected. *"Sisken projects a two percent fuel efficiency improvement through reduced EGR ~~(thinner wall DPF, improved SCR cell density, and catalyst material optimization)~~ [ET-18]".*

- There is considerable overlap in section 2.3.5.1 Variable Displacement Lube Pump with the previous section. Earlier section addresses several references that benchmarked variable oil pumps. Similarly, the section closes with one statement on variable speed water pumps, also covered in earlier section. Authors may want to revisit these sections.

**1.2 Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b? Are the selected technologies suitable as the basis for the analysis?**

*1. Regarding the selection of the vehicle and engine technologies*

Overall the technologies chosen follow a rather well established criteria of technologies considered in earlier similar studies (NRC, CalHEAT, NHTSA, etc.). No technology presented here is a "surprise" technology but all are well established and recognized. The report in this regards appears in the conservative side.

The study's modeling work does not consider some technologies that are either entering the transportation market in specific segments or are making attempts to enter. The study could have one the one hands gained a *broader scope* and *provided incentives for future directions* of research and developments if it considered:

- natural gas (specially as municipal fleets begin to require a minimum population in their new acquisitions to be powered by natural gas),

- LPG (where significant fleets of school buses are been fit up with these engines),

- Dual Fuel technologies (a significant technology to reduce particular matter when Diesel is used to ignite natural gas, and to reduce fueling cost), and Dual Fuel technologies being available in the retrofit market.

- Alternative Fuels, specially fuels that have the potential in the long run to be viable substitutes to fossil fuels and provide significant advantages towards cleaner burning and simpler engine platforms (simpler fuel injection systems, aftertreatment systems).

Dealing with these areas would enhance the breath of the report. There may be good reasons not to be present in the final count of the technologies to be assessed but these reasons can be given (e.g., owing to the little government endorsement in the US.)

*2. Regarding the process used for the analysis*

The process is adequate. The criteria for evaluation is the percent in fuel efficiency improvement.

The report may have used a criteria that aligns with the GHG and fuel regulations, Grams of CO2 per ton-mile, Gallons per 1000 ton-miles. This approach may lead to technology recipes that match future target standards.

This reviewer would have opted to include an overall summary table or chart providing in the x-axes the vehicle class and in the y-axes the technology package. This would give a clear indication of the applicability of the technologies. In each category (block within the x-y plot) a range of efficiency improvement may be included based on the discussion of the literature review. The above summary could then put into perspective both the technology selection of the report's Section 3 and how the authors estimates compare with the surveyed literature.

*3. Regarding the range of vehicle models used*

The selection of 5 engine configurations (and two additional "modeled engine versions") appears adequate and well aligned to the selection of four vehicles. The reviewer recognizes the work involved in the comprehensive modeling of each of the vehicle models is *very extensive*. Despite of it, the report is very reasonable in size and reads well.

This reviewer recommends creating a structure to help understand the interface of engine-vehicle-class designation as the report uses different engines for different applications, such as the one given here:

| Class | Vehicle | Diesel | Gasoline |
|---|---|---|---|
| 2a | | | |
| 2b | Ram Pick-up | 6.7 385HP<br>*4.5L model* | 3.5L V6<br>6.2L V8 |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | T270 BOX<br>F-650 Tow Truck | 6.7L 300HP | 3.5L V6<br>6.2L V8 |
| 7 | | | |
| 8 | T700 | DD15<br>*12.3L model* | |

Note that the modeled 8.9L (8 cylinder version model of the ISB 6.7L) appears not to be used in the analysis. It is only described in page 25 but does not appear elsewhere.

## 2. Performance Analysis of Technologies

**2-1. Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?**

*1. Comment on the quality, scope, and rigor of methodology used for the performance analysis.*

**Quality** of the report is regarded as high.

Strong points:

- The expertise behind the report. The authors show a deep understanding of engine and vehicle technologies, the impacts of various technologies on efficiency and emission, implications on vehicle installation;
- The very consistent analysis across the engines and vehicles;
- Selection of a wide range of engines and vehicles.

Weak points:

- The number of cycles used add significant information but the report may suffer from excessive numerical output at the expense of not highlighting the more interesting technologies moving forward after 2018.
- There is no cost-benefit analysis such as “pay-back” period.
- There is no fuel efficiency consideration taking into account freight.

**Scope** is very adequate. The study considered a wide range of engine and vehicle technologies, which are listed in tabular forms for each engine and vehicle.

**Methodology** is rigorous. This is illustrated in the systematic approach of adding technology content on the baseline engine and vehicle and reporting the impact on fuel economy.

**Correction and Typos**:

Page 35: “Appendix D… cannot provide the actual ~~the actual~~ input data used in the simulation runs.”

*2. Is the methodology clearly described and appropriate to the aims of the project?*

The method is clearly described in Section 3.2. Specifically:

- Baseline of engine performance is carried out. This is more **clearly seen on the Diesel engines** however where tests and simulations for key parameters are shown side-by-side. This is **not the case for the gasoline engines**.

- The models are run for existing technologies which could be implemented with specified improvements (e.g., improvement on turbocharger efficiency, improvement on drag coefficient).
- The models are also run with new technologies (previously not present on that platform) and very informative discussions are included (e.g., the application of GDI on a PFI style engine, lean GDI, VVA, etc.)

*3. Is it sufficiently comprehensive and robust to provide credible results?*

Yes, the results are in line with former studies (such as the NESCCAF 2009 report).

The report could be enhanced by providing the a more comprehensive summary of the technologies. For example the results of engine and vehicle could be combined in a mpg or even better freight efficiency g/mil-ton. Results too could be overlaid with current 2017 EPA standards.

**2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?**

Yes. This reports benefits very much on the work and benchmarking programs that SWRI has conducted on these engines and vehicles. The overall report is highly enhanced by this.

On the engine side, the engines and engine technologies were modeled with GTPower – a well accepted tool in the industry. Baseline models were calibrated with experimental engine data. Combustion heat release data from engine testing were in many instances used. The approach allows for accurate representation of overall fuel consumption and CO2 emissions (typically within +/- 3%) and more accurate representation of small changes in fuel consumption and CO2 as a result of a technology change (within 1%).

Some limitations exist, particularly in the availability of turbocharger efficiency maps as an input. Actual maps were not available. The simulations employ “generic maps” and use a scaling factors to match the engine flow requirements. This approach is adequate.

On the Vehicle side, the engine maps generated, including fuel consumption, were fed into SwRI Vehicle Simulator tool. This tool handles a wide range of vehicle technologies including automatic transmissions, automated manual transmissions, and hybrid systems, etc.

The following cycles were examined:

For Ram Pickup: FTP City, FTP Highway, US06, SC03, WHVC, 65 MPH

For the T-270 Box Truck and F-650 Tow Truck: GEM Cycles, CILCC, Parcel Delivery Cycle, WHVC

For the T-700 Tractor: GEM Cycles, WHVC, NESCCAF Long Haul Cycle

These cycles are described in Chapter 3 and in greater detail in Appendix C.

**2-3. Are the assumptions used in the analysis reasonable? Why or why not?**

Yes. The report provides clear assumptions. There are many examples.

- ✓ The section of Technology #5 (page 41) does an excellent job in showing the assumptions and tradeoffs. The removing of Turbocompounding is discussed in light of the requirement to drive EGR (by means of various pathways such as re-matching of the turbocharger, and addition of an intake throttle) or reliance of heavy SCR for NOx control.
- ✓ The reduced energy content of gasoline with respect to Diesel is explained (such as in page 56) which allows the reader to put in context the thermal efficiency of the gasoline engines when the reports are given in mpg.
- ✓ The important feature of "auto neutral at stop" is very well explained (pages 56-57). This feature absent in a Diesel cycle compromises its fuel efficiency. Representative torque numbers are given as well.
- ✓ For the downspeeding option, the report states that torque curves are increased to provide identical vehicle performance at the lower engine speed. It also points out that the higher BMEP requires upgrades to the engine to tolerate higher cylinder pressure. In practice, as it is pointed out, these are likely to be all-new engines (page 84).
- ✓ The paper makes a very good attempt as to asses the engine out NOx that engine manufacturers will gravitate to (page 88). This is a particularly valuable statement to encourage the research and industrial groups to continue to work on fundamental combustion. As the SCR was introduced there has been a considerable slowdown on this work area, under the assumption that NOx provides efficiency. The brief combustion discussion that follows in page 89 is very appropriate.

There are several areas however noted that the study does not consider in depth but are important and challenging to OEM development teams:

- o Aftertreatment heat management and the fuel penalties associated with them (DPF, SCR units have very strict requirements to maintain exhaust temperatures). This is only touched upon briefly (e.g., page 91) but it is believed to require more attention;
- o Start-up and light off of aftertreatment devices and specially what technologies play significant roles in this area;
- o Weight and packaging of components, with special mention to implications in freight efficiency.

Comments are given below for each section of the report.

<u>CLASS 8:</u>

- The selection of a DD15 engine on the T-700 vehicle (rather than the ISX engine which is what the T-700 actually has) is explained but still lingering to this reviewer it the fact that there is **no model-to-hardware true benchmarks** of the actual vehicle-package. For example, the fuel economy number of figures 3.2 and 3.3 are not compared with real world numbers.
- The authors could have included turbo-charger **VNT technology**, though this may have been "inserted" under Technology 12 – higher efficiency turbo.

- The discussion on removal of the APT unit, and the removal of the APT and EGR, show a reduction on pumping of approximately 0.5bar across the lug curve. Nevertheless the BSFC remains nearly unchanged. A change of 0.5 over 17 is approximately 3%. Where may this be going?
- The discussion on *weight distribution* is given significant treatment and can be followed well (page 50). The *resistance values* associated with these are not explained however (at least this reviewer did not follow). Maybe this can be done in the revised version.
- Little discussion is given to **weight of the technologies** (e.g., in the waste heat recovery), where as **freight efficiency** should have been addressed.

TYPOS:

- page 48: *These results are shown in Figure ~~3.6~~ 3.7 below.*
- Page B-14, B-16, B-18, B-22, B-36: GROSS IMEP on figures should read PMEP.

RECOMMENDATIONS:

There should be a study funded on VVA technologies for Diesel engines. This technology is largely omitted in the report given the poor understanding of the impact of the technology on the engine performance.

<u>CLASS 6 (Kenworth T-270 Delivery Truck):</u>

- Whereas the modeling results for the Diesel engine baselines are well documented in Appendix B (includes experimental vs. model results of key parameters such as BSFC, pressures, temperatures, flows), the **gasoline engines in Appendix A are not benchmarked**. Would the authors be able to update the report with a similar treatment?
- *Section 3.3.3.1:* When discussing the base engine technologies a **summary table** that includes the ISB, V8, and V6 engine performance (best BSFC point, peak and rated TQ and speed) may prove to be helpful. It may include salient technology contents as well, as CR, fuel system, air system, EGR, turbo.
- *Section 3.3.3.1:* The reports in this section are given in mpg comparisons. Would the authors consider providing the **results in BSFC** (in addition to what is presented) for a engine evaluation/comparison?
- *Section 3.3.3.2:* May chose to **bold the V6 and V8 comparison to the baseline ISB** on table 3.17. It will help to asses the relative contributions of the following technology additions.
- *Section 3.3.3.4:* The **selection of 10 to 35% friction reduction** (at high and low loads respectively) needs better treatment on Appendix B (page B-33). This particular section could list technologies that contribute to the values chosen.
- *Section 3.3.3.9:* For the lean burn GDI, is it possible for the report to be more specific as to how much **pumping losses and spark timing** contribute to the gains presented? These settings may be included in Appendix A (near page A-10). Were other contributors part of this gain, such as reduced heat transfer?

- *Section 3.3.3.9 and 3.3.3.15:* **What temperature values were selected** to allow for optimum aftertreatment durability and conversion efficiency? How accurately is the GT power modeling regarding exhaust temperatures? Appendix B-40 shows 25 to 50C deviation for the ISB case.
- *Section 3.3.3.10:* What is the effect of added EGR on combustion efficiency and would this affect the efficiency numbers presented here?
- *Section 3.3.3.14:* The statement that "The benefit from the compression ratio increase is partly offset by a reduction in **combustion efficiency**" is not clear and may not be accurate. Authors may want to explain or reconsider statement.
- *Section 3.3.4.2:* The reduction in Cd of 15% may be further elaborated in Appendix C (page C-13). **What are the technologies that contribute** to this reduction? Can these be inserted in the Appendix?

TYPOS and CORRECTIONS:

- page 61: "in this case, 600 to ~~6,000~~ 5,500RPM". [Data in appendix reports 5,500rpm for the V6 engine).

<u>CLASS 6 F-650 Truck:</u> This section follows closely on T-270 Truck discussion. Same comments apply here as to the earlier section. Addressing these on the T-270 section would be sufficient.

TYPOS and CORRECTIONS:

- Section 3.3.5 Page 69: The first paragraph is identical, and the following one nearly identical, to that of page 54. May read better if referenced to the earlier section.
- Figure 3.24 shows the Y-axes and title overlapping. Please correct.

<u>CLASS 2b-3 Trucks - Ram Pickup Truck:</u> This section too follows closely the CLASS 6 sections.

- Section 3.3.6.2 Page 82: The discussion could be improved by making explicit references to the engine under consideration. The discussion on each of the engines follows the figures, but the text could be more explicit stating what engine is being discussed.
- The paragraph starting "As with the medium duty vehicles…" in page 83 should start by making reference that the discussion pertains to the V8. The later "large engine" would be better understood.

<u>TRADEOFF BETWEEN FUEL CONSUMPTION AND CO2</u>: This portion of the report is short but very informative. The report could be improved by adding:

- Representative **fuel usage required by SCR and DPFs** (fuel required to maintain the functional minimum temperature requirements, fuel required to bring the DPF to temperature on typical regeneration events), including the estimation regeneration duty cycles associated with the drive cycles selected here (page 86).
- It is unclear why the tradeoff study is focused on the larger vehicles only (page 86). Could this be **extended to MD sector**?

- The discussion on the 0.2gNOx engine out NOx needs to be **properly referenced**. The response of NOx to BSFC will depend much on the technologies that the engine bears, such as fuel injection pressure range, close coupled injections, the air and cooling system, the combustion bowl-to-injector match, etc. (page 86). The 20% appears to be too large of a number for the reader to walk with. Data is available from the DEER meetings by Cummins, CAT, and Navistar that show less of a gap, and a gap that depends on technology content.

- The discussion on Key Limiting Issues (page 88) is excellent. The authors on point 1 make a very revealing comment regarding the best engine efficiency point versus the "real world" operation point or the "regulatory cycle point". The paper could **further elaborate** on this, specifically, how to limit the gap between the second and third, the first, being more of the OEMs effort to align engine and vehicle modes of operation.

**2.4 Are the <u>findings and conclusions</u> adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.**

The report is very thorough, systematically listing the findings per technology. The report focuses on the quantitative assessment of technologies across engine and vehicle. During the narrative, the authors make insightful remarks pertaining to each category. The report however <u>does not</u> provide conclusions or 'final remarks'.

For example, the authors make significant remarks to understand the context of the technologies examined. <u>*This contribution and its importance to industry and regulators cannot be undermined.*</u>

- It cautions the reader in several instances of the implications rendered by removing the EGR loop, where the result of reducing the pumping losses will need to be assessed with very high NOx output from the engine and the greater requirements expected from the aftertreatment systems.

- Identifies current cost comparisons between the MD diesel and gasoline engines (e.g., in the case of the F-650 Class truck, approximately $9,000), and the issues with the application of gasoline technologies onto more severe applications.

- Similarly, the authors present the implications of E10 on fuel consumption penalty.

- Many other examples are cited.

However, as noted, there are <u>*no conclusions section in the report*</u>*.* The report should include a conclusion section, different than the summary provided in the executive section. Oftentimes reports limit the conclusions by summaries of the findings (such as done here in the Executive Summary), but we hope the authors can provide more value by synthesizing conclusions, a verdict on the technologies assessed.

## 3. Evaluation of Testing and Simulation Approaches

**3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.**

*1. Adequately review relevant fuel efficiency metrics that take vehicle work and use into account?*

The report attaches on Table 4.1 the "type of regulation" and the "metric" used. The table would be more informative if also included the requirements (values). **Suggested references**: Regulatory Document 40 CFR Part 1037 (e.g., show the requirements per Table 1037.105-6 for Vocational Vehicles and Tractors).

The discussion that follows is informative, as it illustrates the disadvantages of the miles-per-gallon metric (it is a not linear metric over a range of fuel mileage and is correlated one-to-one with fuel consumptions).

Metrics for units of work are discussed, including ton-mile, passenger-mile, and cubic-volume-mile. A practical example is used to illustrate the payload effect in a long combination vehicle. Later in this section, the report concludes with a revisit to the simulations of Section 3 with an emphasis to show the dependency of technologies on both drive cycles and payload. The discussion is particularly insightful to show that some technologies have a large dependency on these two parameters.

This reviewer agrees with the assessment that the metric of gallon/100 bhp-hr may not be the most adequate and may not be an improvement over the earlier metric of g/bph-hr. **Suggested reference** to be placed in the text at this point is the Federal Register Vol. 76. Sep 15, 2011, Rules and Regulations (page 57141). A web link will be useful.

*2. Engine efficiency test procedures, vehicle efficiency test procedures*

The engine efficiency test procedures are covered well by subdividing them in three categories, (1) technologies where the current tests certification procedures do well, (2) technologies where too small of an impact would compete with the uncertainty of the of the certification tests, yet an estimate can be made via accurate bench testing (e.g., oil pumps) or modeling (e.g., adding a clutch in an air compressor) and (3) specific technologies that would not appear on an engine-only certification, the example provided here is downspeeding.

A side comment – in the realm of HD engines the application of variable water pumps and oil pumps can be significant and its impact recorded in the certification cycle. The report may state that these technologies can be lumped into category (1) above. **Suggested references**: Same as used in the literature review on these components by Daimler and Navistar.

The vehicle power demand section describes the GEM model and its inputs. The report offers particular insight of VSL and AES to real-world application. The discussion continues to technologies that are not directly captured in the GEM model. As with the engine discussion, many of these technologies can be benchmarked on dedicated stands to calculate the fuel savings.

Section 4.4.3 deals with SET test points. The data represented in this section from a VOLVO sample of HD long-haul trucks is very informative but needs to be better described and put in the greater context of other manufacturers. The data reflects a significant downshifting. There are many HD applications that will show a different histogram (inter-city, hills, mountains, etc.)

The SET test points are in principle a good and simple approach to estimate the overall power plant efficiency. This reviewer agrees that the right weights need to be updated. Engine and vehicle engineers oftentimes asses drive cycle fuel economy with specific weights to each point according to the drive cycle their vehicles operate in.

Similarly Section 4.5.2 which deals with the FTP test points. The report shows another sample of VOLVO vocational trucks. The data is informative but it would be best to have a wider sample from other manufacturers.

*3. Efficiency simulation approaches?*

Several thoughts comes from the information provided in this section:

One is the opportunity to provide tools to customers, be it large or smaller fleets, to optimize the specifications of vehicles, similarly to what OEMs have developed. Rather than stand-alone, these tools could be tied into the regulatory process to better match engine rating, transmission type, axle ratio, payloads typically used, drive cycles driven.

Second, is the introduction of accurate instant and 'averaged' fuel performance estimates by the vehicle. Its implementation would need to be studied in detail, specially when needing to update the load of the vehicle. This could be expressed as stated in the regulations (e.g., grams CO2/ton-miles or gallons/ton-miles for the vehicle or per bhp-hr for the engine). This may be done with accurate flow meters or a reliable fuel map tables (which may not be always very accurate).

TYPOS:

Page 98, * CFD analysis, or [Constant speed testing]

Page 98, • ~~Constant speed testing~~ Steer…

Page 100, routes where smart ~~of~~ [or] GPS-based cruise control

Page 102, Section ~~7.2~~ 4.2

Page 103, Section ~~7.2~~ 4.2

Page 105, were evaluated in Section ~~5~~ 4.2.2

Page 111, the ~~FPT~~ FTP cycle clearly over-represents

## 4. General Comments

### 4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

Organization: The organization follows a logic structure, providing a review of regulations, review of engine and vehicle technologies, and a detailed performance analysis of technologies beyond 2018 model year products. The review closes with an evaluation of testing an simulation approaches, and recommendations for tractor-trailer and vocational vehicles.

Readability and clarity: The report reads well. The more technical discussions are added in the appendices, which are well documented.

The report needs a Conclusion Section (different than the Executive Summary).

Suggestions regarding formatting:

- Generally, figures may be formatted to match the text font size (and style optionally). The legends, titles, and numbers appear too large. Other figures which appear from other sources, have very small font axis titles (e.g., Figure 4.1).
- Figure and Table titles are capitalized and bolded. The sheer size of the these titles "hide" the report section titles. Consider reducing the font size of the figure titles or not capitalizing nor bolding.

A detailed list of suggestion were provided under the "Performance Analysis of Technologies". Here we collect suggestions for the "Executive Summary":

- HD pickup truck table shows 10,000lb GVWR. An asterisk may be inserted to indicate that it was examined at 25,000lb when pulling a trailer (page v).
- The 6.7L Diesel referred in paragraph 3 appears to be the high HP application – please clarify as there are two rating for this engine (page vi).
- Mention of a 4 cylinder version of the Diesel is made, but this is the first time. May clarify that this is a 'modeled' based on the ISB (page viii).
- Subsequent paragraphs beginning with "Section 4.x" could provide more of a summary. Sentences like "*some technologies perform best on drive cycles that emphasize low speed, light load engine operation, while others prefer high speeds and loads*" (Section 4.6) should be avoided. A more explicit address of what technologies apply would be best.

### 4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?

Generally, the report does a very good job in providing the necessary detail to adequately understand the impact of the technologies in the fuel efficiency improvement roadmap. The text is well coordinated with the appendices – which are very well organized, describing both engines and vehicle modeling efforts.

The report could be enhanced by providing additional detail in

- Fuel penalties associated with the aftertreatment;
- The actual technologies and hardware used to Appendix C to account for the Cd and Crr improvements (page C-13,14),
- How are the weight reductions accomplished, what components contribute to the weight reduction, what materials are being introduced (page C-15)?
- Incorporate and document in the report the effect of weight in the estimation of fuel efficiency.

**4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?**

Strengths:

- Excellent simulation study throughout a very comprehensive list of engine and vehicle technologies. The expertise behind the report is manifested as the authors show the impacts of various technologies on efficiency and emissions, and implications on vehicle installation;
- Very consistent analysis across the engines and vehicles;
- Very informative, brief background descriptions at the technologies presented;
- Methodology used is thorough as illustrated in the systematic approach of adding technology content on the baseline engine and vehicle and reporting the impact on fuel economy;
- The models are run for existing technologies which could be implemented with specified improvements (e.g., improvement on turbocharger efficiency, improvement on drag coefficient).
- The models are also run with new technologies previously not present on that platform and are accompanied by very informative discussions (e.g., the application of GDI on a PFI style engine, lean GDI, VVA, etc.);
- Engines and engine technologies were modeled very well with GTPower. Baseline models were calibrated with experimental engine data, including heat release data from engine testing;
- Engine maps were fed into SwRI Vehicle Simulator tool. This tool handles a wide range of vehicle technologies including automatic transmissions and automated manual transmissions.

Weaknesses:

- The engine simulations are generally more detailed than the vehicle side. For example, no detail (what features) is given regarding the percent reduction in aero drag or rolling resistance;
- The report present savings with respect to miles per gallon. Yet the regulations are prescribed in terms of gallons per ton-millage. The presentation of results with respect to ton-millage would seem more appropriate and useful;

- There is little consideration to weight and packaging of components, with special mention to implications in freight efficiency;
- There is no cost-benefit analysis such as "pay-back" period;
- There is no quantitative analysis of aftertreatment heat management and the fuel penalties associated (DPF, SCR units have very strict requirements to maintain exhaust temperatures), start-up and light off and technologies, impact on certification. All these play significant roles in product development;

**4-4. Please provide any other comments you may have on this report.**

The report could have added more innovative technologies that may be seen in production:

- Some level oh hybrid, e.g., the mild-hybrid concept program evaluated by John Deere and International under the DOE program (Electric Turbo Compounding… A Technology Who's Time Has Come, EERE, 2006 DEER Session) ; hydraulic hybrid (ref. Hydraulic Hybrid Vehicle Technologies , Clean Technologies Forum, Sacramento, CA, September 9, 2008)
- The report should have dealt with CNG. CNG fuel is taking up a larger role in the MD sector and should be considered. The authors could provide a section comparing the merits and challenges that CNG brings.
- The report should have considered alternative fuels. This is a bit of a disappointment in many ways: the more strict GHG, fuel economy, and emission legislations have made our engines more complex, bulkier, more costly, and more expensive in maintenance. OEMs for the most part have limited their effort on the hardware side while not considering the benefits that better fuel formulations could bring. With a little more foresight, the fuel properties and future fuel resources based on bio-derived sources could be aligned with future legislation at this point in time. The efforts of Volvo, Isuzu and others on the use of Dimethyl Ether is an a good example of the potential simplification that this oxygenated fuel can bring to transportation industry. Ref. ORNL/TM-2014/59 Emissions and Performance Benchmarking of a Prototype Dimethyl Ether-Fueled Heavy-Duty Truck, February 2014.
- No mention of "Dual Fuel Technologies" is made here though it has been shown to both contribute to significant simplifications of aftertreatment and improving the combustion cycle efficiency. Refer to http://www1.eere.energy.gov/cleancities/pdfs/cap_dual_fuel_tech.pdf.

**5. Overall Recommendation**

**5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.**

I find the report acceptable with minor revisions.

**Please justify your recommendation:**

The report presents an excellent simulation study throughout a very comprehensive list of engine and vehicle technologies. It is very informative as the report includes valuable background descriptions of the technologies.

The process and criteria for evaluation is the percent in fuel efficiency improvement. This is adequate, yet the report may have used a criteria that aligns with the GHG and fuel regulations (e.g., grams of CO2 per ton-mile, Gallons per 1000 ton-miles).

The selection of 5 engine configurations (and three additional "modeled engine versions") appears adequate and well aligned to the selection of four vehicles.

Metrics for units of work are discussed, including ton-mile, passenger-mile, and cubic-volume-mile. A practical example is used to illustrate the payload effect in a long combination vehicle. The report finishes showing the dependency of technologies on both drive cycles and payload. The discussion is particularly insightful to show that some technologies have a large dependency on these two parameters.

Engine efficiency test procedures are covered well by subdividing them in three categories: technologies where the current tests certification procedures do well; technologies where too small of an impact would compete with the uncertainty of the of the certification tests, yet an estimate can be made via accurate bench testing or modeling; and finally, specific technologies that would not appear on an engine-only certification. Examples are used to illustrate these categories.

The report describes the GEM model and its inputs. The report offers particular insight of VSL and AES to real-world application and customer acceptance. Technologies that are not directly captured in the GEM model are listed and explained is how they can be benchmarked on dedicated stands to calculate the fuel savings.

Examination of The SET test points in a portion of data for Long Haul trucks (limited to one manufacturer with downspeeding technology) show that there is a need to reconsider the right weights. FTP cycle too is compared real world data from vocational vehicles (from same manufacturer), reveling differences, though not as pronounced as with the Long-Haul vehicle data.

**Revisions needed:**

1. The literature review, when addressing the current regulations, should include these in a table rather than simply referencing them. The table should include US and other major regulations (EU, Japan, China). It is also recommended that they be accompanied by the industry average numbers and ranges from current model years (2014 – interim).

2. The technologies chosen are in the in the conservative side, rather well established, there being no "surprise" technology. The review could considered other technologies that have had some presence in the MD-HD vehicle market. This should be a "minor" revision, possibly an added section on the review chapter:

- Natural Gas – the report can provide important benchmarks and balanced guidance regarding NG vehicles with respect to Diesel powered units (benchmark fuel efficiency, cost of fuel, capital investment);
- Liquid Petroleum Gas power plants, currently being offered in fleets of school buses, have less power than Diesels, are quiet, clean, and provide a good cost of operation – the same benchmark as above would provide much value.
- Dual Fuel technologies which provides a significant technology to reduce particular matter and reduce or eliminate the DPF when Diesel is used to ignite natural gas, and can reduce fueling costs,
- Alternative Fuels, specially fuels that have the potential in the long run to be viable substitutes to fossil fuels and provide significant advantages towards cleaner burning and simpler engine platforms (simpler fuel injection systems, aftertreatment systems). One such example being DME.
- A technology like Dual Fuel, in the sight of this reviewer, would be as competitive or more feasible than the Rankine waste heat recovery".
- Dealing with these areas would enhance the report. It would contribute to the long term perspective of highlighting technologies that can significantly impact transportation efficiency.

3. Create a table to help understand the engine-vehicle-class designation used in the report. Also clarify if the 8.9L modeled engine is used – if not used it may be best remove the statements on the 8.9L engine from page 25.

| Class | Vehicle | Diesel | Gasoline |
|---|---|---|---|
| 2a | | | |
| 2b | Ram Pick-up | 6.7 385HP<br>*4.5L model* | 3.5L V6<br>6.2L V8 |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | T270 BOX<br>F-650 Tow Truck | 6.7L 300HP | 3.5L V6<br>6.2L V8 |
| 7 | | | |
| 8 | T700 | DD15<br>*12.3L model* | |

4. The report should include a conclusion section. This should be different from the Executive Summary.

**COMMENTS SUBMITTED BY**

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## 1. Literature Review

**1-1. Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included this section and explain why they would be helpful.**

(1) Fuel saving Technologies

- The literature review appears to be comprehensive and to include key data sources for most available fuel savings technologies for MD/HD vehicles and engines
- Specifically for electric accessories (Section 2.4.2.7) there may be other data sources available detailing in-use experience with electric cooling fans on transit and coach buses, as this approach has become more common in the past five years.

(2) Market Segmentation of Fleets

- Other data sources on market segmentation may be available. For example, in 2009 the International Council on Clean Transportation produced information on market segmentation by vehicle type, based on vehicle registration data collected by R.L. Polk & Company (attached)
- It is difficult for the reader to assess the validity of the chosen CalHEAT market segmentation approach because the report does not contain sufficient information describing it. There should be examples of the types of vehicles that would be included in each of the six segments, especially the differences between segments 2, 3, and 4; i.e., what is the difference between a Vocational Work Truck and a Work Site Support Truck? Which of these segments would the following vehicle types fall into: transit bus, coach bus, school bus, refuse truck, dump truck, utility truck, concrete truck?

  Also, there should be some discussion of the percentage of in-use vehicles, annual miles, and annual fuel use accounted for by each of the six segments.

(3) Current and Planned MD/HD Fuel Economy regulations in Markets around the World

- This section appears comprehensive with respect to the U.S., China and Japan, and mentions Canada, but does not include any discussion of other major vehicle markets including Mexico, Brazil, and especially the European Union.
- It would be helpful to the reader to include a table that briefly summarizes current and future regulatory approaches in each country/region.

**1.2 Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b? Are the selected technologies suitable as the basis for the analysis?**

- In general I find the vehicle/engine combinations chosen for this study to be appropriate for the purpose of the analysis and to adequately cover the range of 2b – 8b vehicles, given understandable limitations of available time and money for the project. The RAM pickup, T-270 box truck and T-700 tractor are clearly the three most important vehicles to include, as they fully and adequately represent vehicles responsible for the vast majority of annual fuel use from the medium- and heavy-duty fleet. The rationale for inclusion of the F-650 tow truck is less clear, and I believe it should be explored a bit more in the text. Presumably the T-270 box truck and F-650 tow truck are together intended to represent Class 3 – 8 Urban Vocational Work Trucks, Class 3 – 8 Rural/Intracity Work trucks, and Class 3 – 8 Work Site Support Trucks, in accordance with the CalHEAT market segmentation discussed in section 2.1. I agree that it is appropriate for both of the modeled vehicles representing these segments to be Class 6 vehicles, and that one of them should be a box truck. However, because there is very little discussion in the text about which types of vehicles and duty cycles cover each of these segments, it is hard for the reader to evaluate whether or not the chosen tow truck is an appropriate second vehicle to represent these segments along with a box truck. In particular it would be helpful to understand the importance of PTO driven equipment on vehicles within any or all of these segments, and how/whether for this analysis the tow truck does (or does not) represent vehicles with PTO driven equipment.
- The selected engine models, engine technologies, and vehicle technologies are suitable as a basis for this analysis, and I believe that they reasonably cover the full range of technologies that would be available to improve medium- and heavy-duty truck fuel economy after 2017.

**2. Performance Analysis of Technologies**

**2-1. Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?**

- The methodology used to evaluate the chosen engine and vehicle technologies was appropriate to the aims of the project, and was clearly described.
- The methodology used to evaluate the chosen engine and vehicle technologies was comprehensive and robust enough to provide credible results.
- One area that requires further description/elaboration is the specific reasoning for the choice of vehicle models used for the analysis, and the choice of drive cycles modeled for each vehicle. Specifically, I believe that there should be text and a table which specifically maps the chosen vehicles and drive cycles to the six CalHEAT vehicle segments discussed in Section 2.1 – i.e., which vehicle(s) and which drive cycle(s) are meant to represent each of the six vehicle segments. To the

extent that there is some portion or aspect of one or more vehicle segments that is not addressed by this analysis that should also be discussed briefly.

- Figures showing the speed/time trace for each drive cycle used in the analysis should be included in the body of the report or in an appendix. On page 34 it says that the drive cycles are "described in detail in Appendix C" but they are not.

**2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?**

- The models used were appropriate for the analysis and appear to have been correctly applied.

**2-3. Are the assumptions used in the analysis reasonable? Why or why not?**

- The assumptions used in the analysis appear to be reasonable.

**2-4. Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.**

- The findings and conclusions are adequately supported by the data.

**3. Evaluation of Testing and Simulation Approaches**

**3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.**

*(1) Fuel efficiency metrics that take vehicle work and use into account*

- This section adequately reviews, summarizes and presents available data on fuel efficiency metrics

*(2) Engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.)*

- The discussion of "power pack testing" on page 97 indicates that "The powertrain test cycle would include specification of the powertrain output shaft speed and torque as a function of time, to simulate a given vehicle drive cycle chosen by the regulators". While I agree that power pack testing is a relevant and useful method for certifying certain technologies, it should be noted that there are no generally accepted "powertrain test cycles" that correspond to any commonly used drive cycles such as those used for modeling in this project. While development of such a powertrain cycle is conceptually straightforward it would require making a number of assumptions about vehicle configuration, including power to weight ratio and transmission and rear end gear ratios. The use of different assumptions for these parameters would result in different shaft speeds and torques as a function of time. One might need to develop a series of powertrain cycles corresponding to different types/configurations of vehicle operating over the same drive cycle.

- In sections 4.4.3 and 4.5.2 the authors recommend that EPA and NHTSA re-evaluate the use of the SET and FTP engine test cycles for certification of compliance with engine fuel use and GHG standards, in order to better match average in-use engine performance. While I do not disagree with this recommendation, I believe that the discussion should highlight the fact that these test cycles were chosen by EPA and NHTSA specifically to maintain a direct link between criteria pollutant and GHG certification test procedures. Breaking this link would create the potential for negative, unintended consequences and in my opinion would not be advisable. I would suggest that the appropriate recommendation would be for EPA to re-evaluate the use of SET and FTP for both criteria pollutant and GHG certification, but to maintain common procedures and test cycles for both.

*(3) Efficiency simulation approaches*

- In section 4.5.1 the authors highlight some vehicle technologies that are not currently captured in GEM for vocational vehicles, but which could be used to further reduce fuel use from these vehicles. Several of these technologies could be simulated by GEM without structural changes to the simulation model (weight reduction, Cd reduction) but most could NOT. GEM specifically cannot simulate the effects of the most promising approaches (AMT, neutral idle, reduction in parasitic loads). The authors should make recommendations for how GEM should/could be modified to account for these technologies and/or offer thoughts on alternative certification approaches.

## 4. General Comments

**4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.**

- It would be very helpful to the reader to include a table in the executive summary which summarizes the findings which are described in the text (range of % fuel reduction for each technology/approach modeled)
- Otherwise I believe that the report is well organized, clear, and readable. I do not believe any major changes are required.

**4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?**

- The report and appendixes are very detailed and they thoroughly document the methodology and results of the study.
- To aid the reader in fully understanding the context and implications of this study I recommend that additional information be added in the following areas:

  1. Executive Summary: Add table summarizing the results discussed in the text (see response 4-1)
  2. Section 2.1: Provide additional information about the CalHEAT vehicle segmentation approach chosen to organize this study, including: descriptions of the types of vehicles included in each

of the six vehicle segments, and estimates of the percentage of in-use vehicles, annual vehicle miles, and annual fuel use and GHGs accounted for by each segment (see response 1-1)

3. Section 2.2.2: Add discussion of fuel economy regulations in the European Union, Mexico, and Brazil and add a summary table comparing approaches in each region (see response 1-1)

4. Section 3.2: Include a more complete discussion of how the vehicles and drive cycles chosen for this study map to the CalHEAT vehicle segments used as an organizing principle for this project. Specifically map the modeled vehicle(s) and drive cycle(s) to the vehicle segments that they represent. Discuss any significant sub-sets of each segment not covered by the study. Specifically address vehicles with significant PTO use to power vehicle-based equipment and how they do or do not fit into this study (see responses 1-2 and 2-2)

5. Section 3.2: Include figures showing the speed/time trace for each drive cycle used in the analysis, either in the body of the report or in an appendix (see response 2-2)

**4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?**

- The strongest part of this report is section 3, the discussion of the results of the engine and vehicle technology modeling. I also believe that section 3.4, the discussion of NOx/fuel economy trade-off, is very well presented and important. Section 4.6, discussion of effects of drive cycle on fuel economy benefit from different technologies, is also very well presented.

- The weakest part of this report is the description of how the vehicles and drive cycles that were modeled were chosen, and specifically the linkage to real-world vehicle segmentation, to provide appropriate context for the reader to understand the relevance and implications of the work. See response 4-2 for specific suggestions for improvement.

**4-4. Please provide any other comments you may have on this report.**

- In section 3 there are a number of comparisons between the modeled fuel economy and fuel use of the same vehicle with both gasoline and diesel engines. The text points out that the efficiency differences between diesel and gasoline engines are not as large as implied by the stated differences in MPG, due to higher energy content of diesel relative to gasoline. However, the text does not mention the differences in projected CO2 emissions for the gasoline and diesel options. Given that this study is in support of joint EPA/NHTSA regulations of both fuel use and GHGs, I think that it would be instructive and helpful to the reader to include discussion of the relative GHG emissions (g/mile) from the gasoline and diesel engine options modeled.

- On page 78 there appears to be a mistake in the text. The text says “Figure 3.26 below shows the fuel economy performance of the F-650 truck with the three engines in their baseline form, all evaluated at 50% payload” while the label on Figure 3.26 indicates that it shows fuel economy performance for the RAM pickup.

## 5. Overall Recommendation

**5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.**

- I find this report ACCEPTABLE WITH MINOR REVISIONS. See responses 4-2 and 4-4 for suggested changes. The analysis appears to be thorough and appropriate to the task, and the methodology and results are thoroughly and clearly described. The suggested minor revisions will provide the reader with better context to understand the relevance of the results to the real world fleet.

**COMMENTS SUBMITTED BY**

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## Literature Review

**1.1 Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included this section and explain why they would be helpful.**

The document does not contain an extensive literature review on market segmentation – there are only two non-CalHEAT references. It describes that the CalHEAT approach was adopted with input from NHTSA. Some additional info should be included justifying the reasons for adopting the CalHEAT segments (of which I am sure there are good ones.) Basically, explain in a little more detail why adopting CalHEAT segments was the right decision for the work reported on in this document.

The discussion of the fuel economy regulations has numerous references but does not aggregate/summarize them into any useful form to allowing the reader to gain knowledge. It basically states that the references exist with little information being given to the reader. This is in contrast to the technology section which provides a snapshot summary of the cited reference.

There is no specific discussion of the European Union in this section of the document in regards to fuel economy regulations.

The fuel saving technologies section appears to have sufficient selection references. There are almost always more references out there – this appears to cover the topics with an appropriate amount.

**1.2 Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b? Are the selected technologies suitable as the basis for the analysis?**

The process used in conducting this part of the literature review is not well stated. If the process is felt to be important (which I think it is) then there should be a brief description of the methodology used. For instance, documenting the search terms and the databases used to search at a minimum. Also some idea of the overall goal, such as: 1) Find technologies capable of >X% improvements in the > 2018 time frame; 2) Find at least two credible references for each technology; 3) Included references will be biased towards more recent and more reputable organizations ; *etc*. From this, it would be clear how the technologies reported on were arrived at.

In terms of technologies, I feel that the list serves as a suitable basis for the analysis.

At times, there is a need to better distinguish which fuel certain technologies apply to. For instance, in 2.3.2.1 EGR is discussed. The statement is accurate for Diesel engines but not for gasoline engines which generally have efficiency gains with moderate amounts of EGR. This is more of an issue of technical clarity than accuracy.

## Performance Analysis of Technologies

**2-1. Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?**

The approach used is credible as it explores a wide range of drive conditions and vehicle states (payload.)

A recommendation would be a limited sensitivity analysis to understand how model calibration errors would propagate through the process. In a project like this that require a great deal of model assumptions and understanding how these effect results is important. I do not think a sensitivity analysis of every single case is likely possible or necessary, however, a "spot check" of a few of the (highest performing?) technologies would be appropriate. I think this would improve the overall conclusions.

The report provides a great deal of data and succinct discussions of each relevant case. I feel that a strong overall summary of the technologies is necessary to provide a clear statement of the efficacy of the different technologies. This could simply be a bar that shows the average impact of the technology on each of the cycles, average for the highway and city cycles, or some kind of cycle weighted average based on an expected mission profile for the particular vehicle class.

**2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?**

The engine and vehicle modeling approach is reasonable for the scope of the analysis. Like all models, sufficient validation must be conducted in order to have confidence in results. When extending the model beyond the initial calibration, it is doubly important to have good confidence in the model and that the model be of appropriate fidelity to capture the effects of the extensions (*i.e.,* added technology) or modifications (*i.e.,* changing displacement, friction, *etc.*) There are some potential concerns addressed in charge question 2-3 regarding the calibration and application of the model – however, the models chosen for the study are deemed appropriate.

**2-3. Are the assumptions used in the analysis reasonable? Why or why not?**

On A-2, the data used to calibrate the 3.5L engine is listed as six signals. This list is quite short and is missing some key parameters, such as throttle. The same concern exists for the other three engines. I assume this is an oversight – if not then some explanation needs to be given on the approach. In the validation plots, agreement in air mass is required to demonstrate model accuracy. The quality of the air agreement of the model is not specified, only that it was "close to the experimental data." With the approach taken, adjustments to the heat transfer model could very easily mask significant errors that have a root cause in issues with the air modeling. This would weaken conclusions made from the model. The same comments exist for A-17, section 2.1, regarding the baseline V-8.

On A-10, there is insufficient information to evaluate the approach to developing the GDI engine model. There is no discussion in particular of how the stratified charge mode would be handled from a combustion

perspective. There is also some optimization that needs to occur for the mode transitions and within the mode regarding AFR which should be discussed as well.

On A-12, there is insufficient information to evaluate the approach in modeling the HEDGE. Some "rule-based" guidelines are provided for modifying the combustion model the basis of which is not provided. The same argument applies to EGR selection and cam phasing. I understand that fully modeling this is outside the scope of the work, but there needs to be additional explanation and a validation that demonstrates that the assumptions led to results comparable to experimental work. The same comments here apply to section 2.3 on A-20.

The approach used in Appendix section 1.2, 1.3, 1.6, 1.7 and 1.8 appears sound given the constraints of the study.

On A-19, section 2.2, the approach used regarding modeling of the GDI engine is not described in sufficient detail. I understand the limitations of GT-Power and difficulty in modeling combustion, however, the assumptions made are not backed up by any data. What is the added pump load and why? Why decrease combustion efficiency by precisely 2%? Furthermore, the resulting BSFC map without any kind of validation. I would think it possible to cite a reference that says you should get a ~2% change in BSFC on average (or whatever your target is.) The approach used in section 2.6 (A-25) requires the same type of justification.

The approach used in Appendix section 2.4 and 2.5 appears sound given the constraints of the study.

The approach used in section 2.7 (A-27) needs some basis for the friction reduction. Why is a reduction of 10% FMEP a valid number? This should be explained.

Figure quality in B1a and B1b (B-4) is poor.

In 1.1 (B-3) the accuracy of the air agreement needs to be shown in addition to the BSFC error. With this type of model it is easy to match torque independently of air by altering heat transfer, friction, *etc.* This comment is similar to that stated previously with the gasoline engines.

The approaches used in appendix B appear valid provided the baseline model is accurate. The changes described are all consistent with the capabilities of this class of model and should yield appropriate results. There is not a great deal of info provided on many of these so it is difficult to truly ascertain the validity of the approach without going into great detail – but I have no reason to doubt the approach and execution from what is presented.

**2-4. Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.**

I have no reason to disagree with conclusions made in this section of the report. Per comments above, I do feel that there could be a greater level of validation provided to give greater confidence in the ability of the modeling approach to yield accurate results.

## Evaluation of Testing and Simulation Approaches

**3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.**

Fuel efficiency metrics that take vehicle work/use into account: The report does not succinctly or cohesively describe fuel efficiency metrics that take vehicle work/use into account. It contains uncited statements and informal language like, "Twenty years ago, almost every driver did upshifts only as the engine approached the high-speed governor." (page 100) It does bring up a good number of real difficulties in developing metrics but does not offer much in the way of direction. I feel that there is a great deal of good information here but it is not presented in a way that strongly supports the goal of the report.

Engine/vehicle efficiency test procedures: There is a general review of engine/vehicle efficiency test procedures. It would be helpful to have an additional section that summarizes the approaches from each of the regulatory groups discussed. As it is, the information is relatively diffuse and future readers could benefit greatly from an overall summary comparing/contrasting the different approaches.

Engine/vehicle efficiency simulation: There is not a strong discussion of engine/vehicle efficiency simulation approaches. This issue is dispersed throughout the section and not dealt with in great detail. I would recommend a separate section be devoted to this and relevant information pulled into it and summarized. Of particular interest would be the type of models used and how they compare to something familiar in the US like GEM.

Overall: This section is not as well-written as other parts of the report. It has a lot of good references and discussion but could benefit from being refocused on the specific tasks.

## General Comments

**4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.**

With the exception of the section 4, I feel that the document is fairly well organized and readable. I made comments previously regarding section 4 with some specific recommendations.

**4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?**

I have no further comment then those made earlier. The most critical point would be to add as much validation and justification of assumptions as possible to the baseline engine models as these drive the accuracy of the technology assessment. I was also suggest that wherever possible the results from the analysis be compared against experimental data in as clear as manner as possible. This lends great confidence in the modeling approach to extrapolate beyond the baseline model.

**4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?**

From having done similar simulation work, I feel that this represents a very serious investment of engineering effort and, despite some requests for clarification, believe the work is quite sound technically.

The weakest part is really the converse of this, in that the modeling approach is quite complicated and based on many assumptions. Without literally sifting through the model and validation data, it is difficult to conclude that each and every simulation case is without fault. The best way to address this is to provide as much validation points as possible, whenever possible. If a paper exists that suggests a 6% improvement in FE and the simulation shows 5-9% - that is a good indication that the approach is valid and this should cited. This is done in many cases but not in others.

**4-4. Please provide any other comments you may have on this report.**

No other comments.

## Overall Recommendation

**5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.**

I feel this report is acceptable with minor revisions for: 1) clarity (section 4 mainly); 2) documentation of assumptions; and 3) additional validation as discussed above. I would state that there is nothing in the report that appears inaccurate, however, in a guiding document like this results should be well vetted as possible. Specific suggestions are described in the previous sections of this review.

**COMMENTS SUBMITTED BY**

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**Peer Review – Draft Report "Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #1"**

*Susan Nelson*
*Managing Member, Blue Stripe Scientific, LLC*
*Greenville, SC*
*15 January 2015*

The following discussion responds to a request by ERG, Inc. to review the assessment of engine and vehicle technologies for potential improvements in fuel economy and greenhouse gas (GHG) reductions performed by the Southwest Research Institute for NHTSA, to assist the agency in formulation of Phase 2 standards for medium- and heavy-duty (MD/HD) trucks. In general, my comments will be provided based on my prior experience and studies related to commercial tires and tire rolling resistance on Class 8 trucks. When it seems appropriate, additional commentary may be added regarding other topics, technologies, and/or methodologies within the limits of my expertise. I hope this review will provide useful feedback, and help support the study authors in producing a final report that provides the maximum contribution to commercial vehicle fuel efficiency improvements.

## 1. Literature Review

**1-1. Does the literature survey described in Section 2 include the key data sources for the three areas of interest: (1) fuel saving technologies for MD/HD engines and vehicles, (2) market segmentation of fleets, and (3) current and planned MD/HD fuel economy regulations in markets around the world? Please describe any key sources that are not included in this section and explain why they would be helpful.**

**Tire rolling resistance.** Several key references discussing the influence of tire rolling resistance on vehicle fuel consumption, but which are not included in the report, are listed below. In general, they constitute a chronological progression in the approach to quantifying and simulating the effects of improvements (reductions) in tire rolling resistance, as characterized by the tire coefficient of rolling resistance, Crr, to lower fuel consumption. The various analyses include lab measurements of Crr, descriptions of full-vehicle track testing, model validation for predictions of fuel consumption, and comparisons of measured and simulated changes in fuel use as a function of rolling resistance. LaClair and Truemner (2005), particularly, demonstrated the linear relationship between rolling resistance changes and fuel savings, and that the slope of these relationships depends on drive cycle. The two subsequent papers build on this analysis to develop methodologies which permit predictions of fuel savings based only on the fuel type, weight of the vehicle, and change in Crr, relatively independently of drive cycle.

- LaClair, T.J. and Truemner, R., "Modeling of Fuel Consumption for Heavy-Duty Trucks and the Impact of Tire Rolling Resistance", SAE Paper no. 2005-01-3550, 2005.
- Barrand, J. and Bokar, J., "Reducing Tire Rolling Resistance to Save Fuel and Lower Emissions", SAE Paper no. 2008-01-0154, 2007.
- Guillou, M. and Bradley, C. "Fuel Consumption Testing to Verify the Effect of Tire Rolling Resistance on Fuel Economy", SAE Paper no. 2010-01-0763, published 04/12/2010.

**Other key sources for vehicle technologies.** The latest update of the continuing studies by the National Research Council (NRC, 2014) concerning technologies for reducing fuel consumption of commercial vehicles was published in 2014. The NRC forecasts the release of a final report on technologies in 2016.

An annual summary of adoption rates of fuel-savings engine technologies, vehicle technologies, and fleet operational practices in 10 major North American fleets has been published by the North American Council for Freight Efficiency (NACFE, 2014), beginning in 2011 and most recently updated in August 2014. The study covers the period from 2003 through 2013. This reference can provide insights on technology penetration rates, particularly from an end-user perspective. While many of the technologies tracked in the NACFE study have been considered and/or incorporated into the SwRI report, the NACFE report also reflects user-driven demand, that is, deployment of new equipment or methodologies which have been seen to be valuable from a fleet viewpoint including not only fuel savings, but also life-cycle costs and maintainability.

NACFE has also produced reports on specific heavy truck technologies, including tire pressure monitoring and maintenance systems (NACFE, 2013), 6x2 axles (NACFE, Jan 2014), options for idle reduction (NACFE, June 2014), and automated transmissions (NACFE, Dec 2014).

Automatic tire inflation systems (ATIS) were mentioned by SuperTruck participants (Delgado and Lutsey, 2014) as an off-the-shelf technology that could provide additional fuel savings via more precise control of tire pressure. For several reasons, ATIS was not included as an element of the technology package considered for Phase 1 rulemaking. If a vehicle market survey can be pursued as part of Phase 2 standards development, it may be possible to concurrently obtain an updated baseline of the extent of tire underinflation in truck fleets, and to reconsider the practicality of including ATIS in future technology packages. A new tire inflation technology under development (but which is unlikely to be of sufficient maturity for several years) is an automatic inflation system that is completely contained within the lower sidewall of commercial tires. This product is described at the following site: http://www.goodyear.com/cfmx/web/corporate/media/news/story.cfm?a_id=1040. The inflation system is an integral part of the tire in this technology, in contrast to tire pressure monitoring systems (TPMS) or ATIS solutions, which can be disabled.

Another approach under study uses lift-axle capability to transfer load across axles in a tandem configuration in order to optimize the effective rolling resistance contribution of the tandem to the overall vehicle. Algorithms were developed based on knowledge of tire load-carrying and traction properties to improve fuel-savings while properly maintaining other functionalities. The improvement comes from exploitation of the small non-linearity of tire Crr as a function of load. Effectively, the tire is more efficient at high loads. (For working purposes, though, this should not perturb other analyses which set Crr as a constant with respect to load.) The patented methodology is described in Clayton and Bradley (2013).

**Market segmentation.** Several industry organizations conduct annual market surveys of fleets in an effort to assess the numbers and types of commercial vehicles in service, fleet operational costs, and trends in miles traveled and vehicle trade cycles. The American Transportation Research Institute (ATRI) has published its most recent analysis in 2014. A copy of the survey questions used is included in Appendix A of the ATRI report.

**Global fuel economy regulations.** An up-to date-summary of worldwide fuel consumption and emissions regulations, both current and planned, is contained in the 2014 State of Clean Transport Policy report by the International Council on Clean Transportation (Miller and Facanha, 2014). In addition to the US, China, and Japan, Canada is the 4th nation to adopt fuel consumption standards for heavy-duty vehicles. At this time, Canada is expected to align with US standards for the period covered in Phase 2 rulemaking. The ICCT report covers both light- and heavy-duty regulatory trends.

The European approach for tire labeling for fuel economy is described briefly by the European Tyre and Rubber Manufacturers' Association. It is an alternative approach for grading tires for fuel consumption, and informing consumers of the fuel efficiency of their tires. The use of up to 7 grade levels for tire Crr is presented, according to measurements using the ISO 28580 tire rolling resistance laboratory method.

**1-2. Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis? Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8? Are the selected technologies suitable as the basis for the analysis?**

The technologies that have been included in the Class 8 tractor-trailer engine and vehicle analysis are appropriate selections for considering future truck capabilities. Technologies in the study report comprise the primary truck fuel-savings developments identified across the previous reviews by NRC (2010, 2014) and EPA-NHTSA (RIA 2011). The current study also includes the most viable approaches being pursued by the four teams participating in the U.S. Department of Energy SuperTruck projects, summarized by Delgado and Lutsey (2014) (with the exclusion of hybrid solutions which are out-of-scope).

**2. Performance Analysis of Technologies**

**2-1. Please comment on the quality, scope, and rigor of methodology used for the performance *analysis of the vehicle and engine technologies described in Section 3. Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?***

Refer to comments under question 2-3.

**2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?**

Selection and exploitation of the simulation models used in the study are consistent with those typically used by other published researchers in the field. Refer to additional comments in the response to question 2-3.

**2-3. Are the assumptions in the analysis reasonable? Why or why not?**

**Tire rolling resistance from coastdown measurements.** Tire rolling resistance inputs to simulations have been obtained from coastdown testing for all study vehicles using SAE J1263 method (directly or with modifications). Coastdown tests are routinely used to calculate the coefficient of aerodynamic drag (Cd) and tire Crr as inputs for chassis dynamometer tests and vehicle simulations. However, there can be difficulties with data obtained in this way for a couple of reasons. First, and the most minor, is

that other friction and drag effects can be rolled into the value of Crr. Second, conditions of the testing, and the speeds at which the data is acquired, can have non-negligible influence on both Cd and Crr (Hausberger, 2011). And finally, it can be difficult to relate coastdown values of tire Crr to those measured on a laboratory test drum under controlled conditions, as discussed below.

When tire rolling resistance is measured on a test drum, the curvature of the drum generates greater deformation of the contact patch and thereby increases rolling resistance relative to the level that would be experienced on a flat surface. Using the formula developed by Clark (1976), the Crr value obtained on a curved surface can be adjusted to flat ground or to any other diameter test drum. The formula:

$$Crr\ (drum) = Crr\ (flat) * [1 + (R(tire)/R(drum)]^{1/2}$$

predicts that a truck tire of 0.5-meter radius would have a rolling resistance level approximately 20% higher on a 1.7-meter diameter drum than on a flat surface, where R(tire) is the unloaded nominal tire radius, and R(drum) is the radius of the test drum. There is some uncertainty in the "true" level of the correction factor predicted by this formula.

Furthermore, there is some speculation that the predicted change in absolute rolling resistance that is observed in going from a laboratory drum to flat ground may be approximately compensated for by increases in rolling resistance associated with road surface roughness. In the case of the Hausberger study, tire rolling resistance coefficients did increase in going from drum measurements to track tests, and not necessarily in the same proportion by tire type. It was also concluded that drum measures of Crr were likely to be necessary to generate appropriate coastdown values for Cd.

Tire Crr from coastdown testing aggregates the effects of steer, drive, and trailer tires into an overall effective tire rolling resistance for the entire vehicle. This is a useful approach for simulation, easing the burden of modeling Crr effects individually by axle. But good data for Crr (and Cd) are critical for the vehicle simulations. The values used in the report may be completely correct, but it is difficult for the reader to make this assessment without: 1) greater explanation of the testing than is given in Appendix C, including whether the tires used were new, partially worn, broken-in, etc.; 2) laboratory measurements of Crr for the tires used on the study vehicles by tire type; and, 3) some selected comparisons of experimental data from whole vehicle road tests with simulations of fuel consumption/MPG shown in the Tables 3.11 and 3.12 (T-700), 3.15 and 3.16 (T-270), 3.19 and 3.20 (F-650), and 3.22 and 3.23 (Ram). This last item would validate both fuel consumption in terms of an absolute value, and more importantly, also validate the slopes of the curves in Figure 3.8.

The linear form of the relationship between $\Delta$Crr% and $\Delta$FC%, by drive cycle, with different slopes according to the drive cycle used, has been demonstrated in the past (LaClair 2005). If the confidence is high regarding the values of the slopes, then knowing the *change* in Crr ($\Delta$Crr) between two tire sets is much more important than having the absolute values of Crr. *Relative* changes in fuel consumption can then be predicted from *relative* changes in tire rolling resistance. See also Barrand and Bokar (2007) and Guillou and Bradley (2010).

Lastly, the text in Appendix C, Section C2.3 reads as follows, but no separate Crr data by tire type is provided.

> "For the tractor-trailer vehicle, separate Crr values were used for the steer tires, drive tires, and trailer tires. For the medium-duty trucks, separate Crr values were used for the steer and drive tires."

**2-4. Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.**

Elaboration of the derivation of Crr and supporting information should be provided as discussed in question 2-3. A more thorough summary of vehicle simulation comparisons with chassis dynamometer data across the baseline vehicles would reinforce the credibility of Appendix C.

## 3. Evaluation of Testing and Simulation Approaches

**3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.**

**Metrics.** The trucking industry has internally tracked a number of key performance indicators (KPI) such as tons of freight moved per year, vehicle miles traveled (VMT) per year, total quantity of fuel consumed per year, proportion of empty miles, miles per vehicle per year, as well as very familiar-sounding KPIs including ton-miles per year, ton-miles per vehicle per year, cost per ton-mile, and cost per ton-hour. Just as ton-miles per year is an indicator of annual freight carrying productivity, an indicator like load-specific fuel consumption (ton-miles per gallon, or the inverse for fuel consumption, LSFC) is an analogous measure of freight efficiency. LSFC should continue to be an appropriate metric.

Alternatively, would it be better to include the weight of the vehicle together with payload in the tons calculation of LSFC? If we apply LSFC based on payload, then a less-than-truckload (LTL) fleet would be ranked as much less efficient than a truckload (TL) fleet, even though the cargo area of the LTL carrier is full. The effect of including vehicle weight would reduce (and sometimes significantly) the difference in efficiency ranking between the two fleets versus payload-only based comparisons. In addition, including vehicle weight as well as payload reduces the efficiency difference in comparisons between classical tractor-trailers and long combination vehicles (LCV). This could make LCVs appear less attractive because the scale of LSFC comparison is smaller. This comment is for reflection only, the current LSFC metric of gallons/1000 ton-miles should function appropriately whether the vehicle weight is included in the load calculation or not.

In the commercial sector, using LSFC as a metric for rulemaking and MPG as a familiar metric by end users may not present such a difficulty. Truck fleet managers are very cognizant of their freight patterns, equipment, and costs of most aspects of their operations. Often, fleets divide their businesses into "sub-fleets" of similar usage characteristics to be able to optimize and track specific

types of applications. They are generally able to properly assess changes in MPG in the context of their own operations.

**Drive cycles and technology performance.** Given all the background information available on the topic of drive cycles, I am only able to add a couple observations here. First, it is outstanding to see a consistent analysis work method applied to illustrate the relative strengths and weaknesses of key technologies across a range of familiar drive cycles. In fact, in my view Section 4.6 is the most impactful section of the report.

How these results can be incorporated into GEM is a challenge. The second point is that there should be an explicit statement of the requirements for a drive cycle, or combination of drive cycles, within this regulatory context. Should a drive cycle be the best possible representation of a particular vehicle's real-world operation? Should it be able to be reproduced in chassis dyno tests as well as on a track or roadway? Should it highlight or mask the effects of particular technologies? Is it acceptable to piece together discrete fractions of usage conditions of existing drive cycles to create an entirely new series of vehicle operating steps for simulation? The "best" strategy for GEM may not necessarily be the best strategy for other purposes such as vehicle or technology design.

**Trailers and drive cycle weightings.** An example of how the trailer tires contribute to the overall effective vehicle rolling resistance (which we might also say is the coastdown Crr of the vehicle) is shown in the following table for estimated axle loads for the T-700 for the 0%- and 100%-payload cases. The effective vehicle Crr(veh) is given as:

$$Crr(veh) = [\ \Sigma_j\ Crrj * Zj] / [\ \Sigma_j\ Zj\ ]$$

where, for this case Crrj is the coefficient of rolling resistance on axle j, and Zj is the total load on that axle. The table shows the role played by the trailer axles in percent of load carried, and percent contribution to the total rolling resistance of the vehicle for the two payload cases. Example tire rolling resistance values are current SmartWay thresholds for steer, drive, and trailer tires. In the zero payload case, it is assumed that the steer axle carries 11000-lb, that the 15000-lb trailer weight is split evenly between the drive and trailer tandems, and that the drive tandem carries the balance. If all tires on the vehicle have the same rolling resistance, then Crr(veh) = Crr(tire). If the tire rolling resistance is different by axle position, as is common, then the percent of weight carried by the axle does not necessarily equal the percentage contribution by that axle to the overall Crr(veh). In this latter case, the value of Crr(veh) depends on the weight distribution by axle (as well as the steer, drive, and trailer tire Crr values).

| Description | Steer Axle Weight, lb | Drive Tandem Weight, lb | Trailer Tandem Weight, lb |
|---|---|---|---|
| ***0% Payload case, Total vehicle weight 33960 lb.*** | | | |
| **Load distribution of empty tractor-trailer*** | **11000** | **15460** | **7500** |
| **% weight carried by axle or tandem** | **32%** | **46%** | **22%** |
| **Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)** | **6.5** | **6.6** | **5.1** |
| **Rolling resistance contribution of axle to Crr(veh), kg/T** | **2.11** | **3.00** | **1.13** |
| **Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T** | | **6.24** | |
| **% Contribution of axle, tandem to total effective vehicle Crr(veh)** | **34%** | **48%** | **18%** |
| | | | |
| ***100% Payload case, Total vehicle weight 80000 lb.*** | | | |
| **Load distribution of 46040-lb payload tractor-trailer** | **12000** | **34000** | **34000** |
| **% weight carried by axle or tandem** | **15%** | **43%** | **43%** |
| **Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)** | **6.5** | **6.6** | **5.1** |
| **Rolling resistance contribution of axle to Crr(veh), kg/T** | **0.98** | **2.81** | **2.17** |
| **Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T** | | **5.95** | |
| **% Contribution of axle, tandem to total effective vehicle Crr(veh)** | **16%** | **47%** | **36%** |

*** Assuming steer axle weight does not vary greatly due to engine weight on axle.**

When aerodynamic optimizations are made on the tractor only, some technologies may add weight, but many improvements to bumpers, mirrors, or existing roof fairings could be accomplished at nearly iso-weight. On the trailer, aero packages can add up to 2200-lbs (Delgado and Lutsey, 2014), or approximately 6.5% of the tractor-trailer weight (without payload). Accounting for both improved Cd and increased weight of aero technologies on trailers slightly reduces the effectiveness of obtaining fuel savings on the 65 MPH drive cycle shown in Figure 4.6. Combining aero and its intrinsic weight on the CARB cycle, shown in Figure 4.7, results in a negative contribution of that technology to fuel savings. The impact may be small due to the small weighting factor of the CARB cycle in GEM for tractor-trailer combination vehicles. But it highlights an example scenario where some technologies may have fuel disadvantages in certain specific applications, but also raises the possibility that those technologies may still be included in regulatory equipment packages due to overall benefits.

Most large fleets using box van trailers have an equipment ratio of about one tractor to every three trailers. Trailers generally accumulate miles much more slowly than tractors – perhaps 25,000 to 35,000 miles/year versus an accumulation of 100,000 miles or more annually for tractors. It will take longer for a fleet to realize its full return on investment for a trailer technology than a tractor technology, even though fuel consumption and GHG improvements are observed on a national level.

## 4. General Comments

### 4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

Information content of the report is very dense. Detailed descriptions of performance results and the trade-offs associated with multiple technologies are often combined into the same paragraph, making

it at times challenging to extract the most important points amid many comparative statements. While not obligatory, some suggestions that might help the reader include:

- Occasionally breaking up some of the longer paragraphs, focusing on only one or two technologies in a single paragraph.
- Using bullet lists within paragraphs to visually separate key points and conclusions.
- State clearly when data is from simulations, lab testing, or track testing.
- Global regulations could be summarized in a table, at least in Section 2.
- The history of the RFPs in the Introduction is confusing, but may be required. It can also be difficult to understand which "SRx" Tasks are in scope and which are not; emphasis should be on what SwRI is being asked to do for the report at hand.

**4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?**

More detailed back-up information to reinforce the appropriateness of the coastdown coefficients, and demonstration of vehicle simulations against experimental track data should be provided, as described in the responses to question 2-3.

**4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?**

Given its potential impact on the definition of future technology packages and drive cycle combinations, Section 4.6 is the strongest part of the report. Any further conclusions that can be derived from data presented in this section would be of interest. For example, are the effects of payload understood well enough across all vehicles and all drive cycles that only one load condition needs to be considered for rulemaking? Are there recommendations of technologies that should move forward and others which should be abandoned?

The weakest part of the reporting is vehicle model validation, which is covered in Appendix C. There is not a sufficiently strong sense of how well the models predict actual fuel consumption of the baseline vehicles. Validation of the slopes for the graphs of changes in fuel consumption as a function of changes in tire rolling resistance (and Cd) can particularly strengthen the report.

Lack of a broader dataset of market segmentation is an acknowledged weakness. This could be addressed in part by other data sources, such as surveys by industry organizations.

**4-4. Please provide any other comments you may have on this report.**

A 30% decrease in tire Crr from today's (2014-2015) SmartWay thresholds based on ISO 28580 would result in the following values: Steer 4.55 kg/T; Drive 4.62 kg/T; and Trailer 3.57 kg/T. The assumed improvement target, Crr=3.93 kg/T, given in Appendix C for the T-700, is not consistent with these levels. Use of large changes from baseline can be beneficial to identify trends in simulations. Setting a potentially extreme level

of rolling resistance reduction as a target may risk compromises of other performances for future tire development.

**5. Overall Recommendation**

**5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.**

I would recommend the report be published with (a) minor revisions to improve readability, and (b) a moderate-level revision to Appendix C, as has been mentioned earlier in this review. Without this additional validation the report is an excellent simulation study, but still a simulation study. With the data, the report is substantially more convincing and provides a solid basis for both rulemaking and future studies of MD/HD fuel efficiency.

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3. Clark, S.K., "Rolling Resistance Forces in Pneumatic Tires", U.S. Department of Transportation, Report no. DOT-TSC-76-74, January 1976, available for download at http://ntl.bts.gov/lib/46000/46400/46414/DOT-TSC-76-74.pdf.

4. Delgado, O. and Lutsey, N. "The U.S. SuperTruck Program: Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies", International Council on Clean Transportation (ICCT), Whitepaper, 2014, http://www.theicct.org/sites/default/files/publications/ICCT_SuperTruck-program_20140610.pdf.

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7. Miller, J. D. and Facanha, C., "The State of Clean Transport Policy: A 2014 Synthesis of Vehicle and Fuel Policy Developments", International Council on Clean Transportation, 2014, available for download at www.theicct.org/state-of-clean-transport-policy-2014.

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10. North American Council for Freight Efficiency, "2014 Fleet Fuel Efficiency Benchmark Study", August 21, 2014, http://nacfe.org/wp-content/uploads/2014/09/NACFE-2014-Study-Report-FINAL-083114.pdf.

11. North American Council for Freight Efficiency, "Confidence Report on 6x2 Axles", January 13, 2014, http://nacfe.org/wp-content/uploads/2014/01/Trucking-Efficiency-6x2-Confidence-Report-FINAL-011314.pdf.

12. North American Council for Freight Efficiency, "Confidence Report on Idle-Reduction Solutions", June 25, 2014, http://carbonwarroom.com/sites/default/files/reports/Idle-Reduction_Confidence_Report.pdf.

13. North American Council for Freight Efficiency, "Confidence Report: Electronically Controlled Transmissions", December 14, 2014, http://nacfe.org/wp-content/uploads/2014/12/Trucking_Efficiency_Transmissions_Confidence_Report.pdf.

14. North American Council for Freight Efficiency, "Tire Pressure Systems", August 15, 2013, http://nacfe.org/wp-content/uploads/2014/01/TPS-Detailed-Confidence-Report1.pdf.

15. SAE International, "Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques", SAE J1263, March 2010.

16. U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA), "Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles", Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.

**COMMENTS SUBMITTED BY**

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# PEER REVIEW CHARGE

## DTNH22-13-D-00298 – Task Order 0003, Report 1

## *"Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #1"*

**1. Literature Review**

**1-1. Does the literature survey described in Section 2 include the key data sources for the three areas of interest:**

**(1) fuel saving technologies for MD/HD engines and vehicles**

The literature review was adequate for this study. Most publications only test a single (or few) operating condition(s). It would be nice to have at least one reference (and a paragraph) on each of the engine technologies and vehicle technologies investigated. Some areas that were lacking references were asymmetric turbochargers and Stoich EGR.

In your literature review on single wide tires, you mention that single wide tires save weight. Is this including the weight of a carrying spare that many trucking companies would choose to do?

**(2) market segmentation of fleets, and**

This question is outside my area of expertise.

**(3) current and planned MD/HD fuel economy regulations in markets around the world?**

This question is outside my area of expertise.

**1-2. Please comment on the selection of the vehicle and engine technologies for performance analysis. Was the process used appropriate to the purpose of the analysis?**

I was surprised by the lack of combustion related technologies. In Section 3.1.1, Engine Technologies, there is the statement that no combustion related technologies are in the list. Isn't "Stoich EGR" considered an engine combustion technology? In addition, the statement that combustion related technologies only offer benefits of 1-2% is not supported by your literature review. Your literature review mentions benefits of 7.4%, >3%, 7.1%, 3-3.5%, and 4%. Many of the technologies that were investigated involved benefits of 1% or less, so why not combustion technologies?

Does the range of vehicle models selected adequately cover the range of Class 2b through Class 8b?

The only concern I have is on representing the work site vocational trucks. How was this analyzed and/or rationalized with the vehicles and drive cycles selected? Many of these work site vocational vehicles do not travel many miles and have an engine loading very different than those shown. In addition, engine technologies may be more important in these cases than vehicle technologies.

The description of how the vehicles were selected was only included in the executive summary.

Are the selected technologies suitable as the basis for the analysis?

The selected technologies gave a variety of options and analysis.

Many drivetrain options were investigated. Have you investigated the option of a continuously variable transmission (CVT) with high efficiency? Another interesting engine technology is having a variable compression ratio.

**2. Performance Analysis of Technologies**

**2-1. Please comment on the quality, scope, and rigor of methodology used for the performance analysis of the vehicle and engine technologies described in Section 3.**

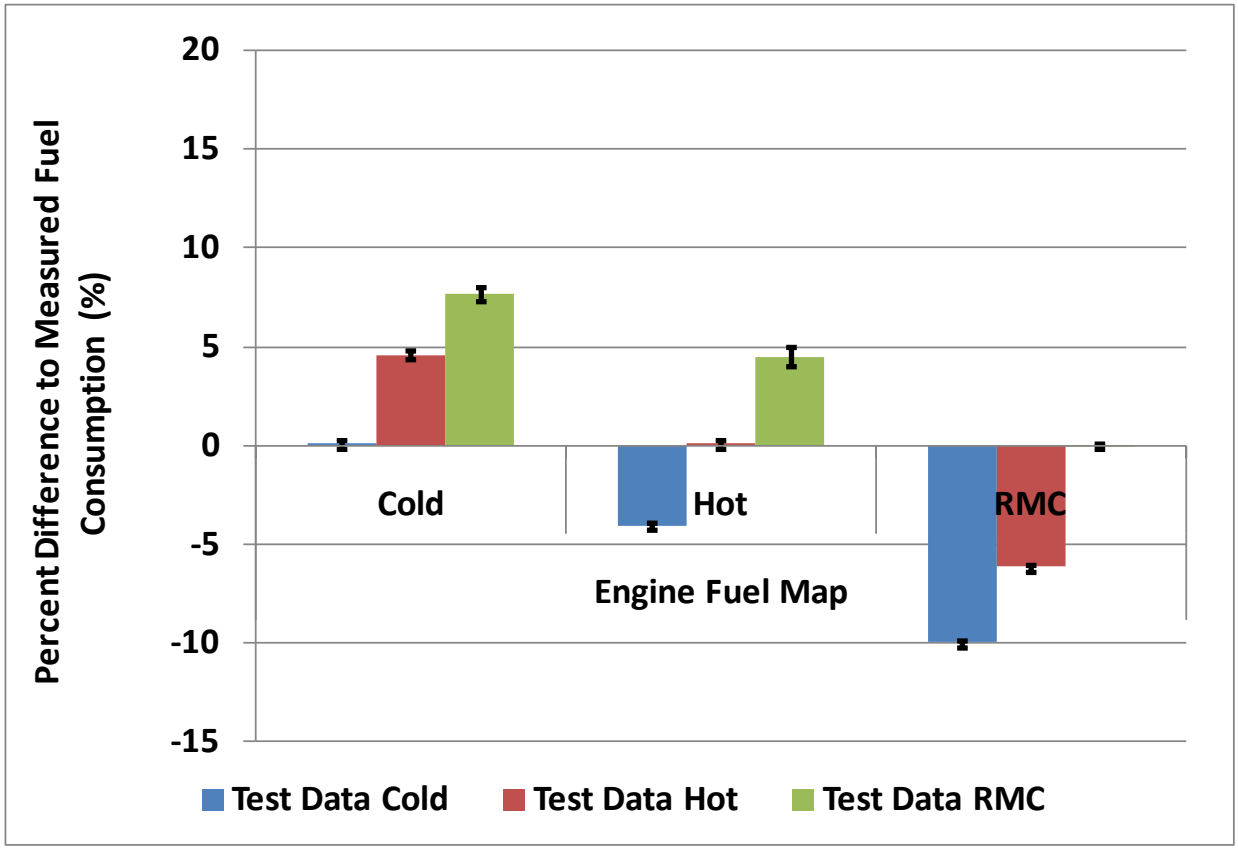
The quality, scope, and rigor were definitely there. Models were extensively calibrated with experimental data when available.

**Is the methodology clearly described and appropriate to the aims of the project? Is it sufficiently comprehensive and robust to provide credible results?**

The model was sufficiently described.

**2-2. Were the models chosen appropriate for the analysis, and were they applied correctly to model vehicle and engine performance? If not, why not and what would you recommend?**

Please speak to the transient influence of the technologies and model. The engine fuel consumption maps were based on steady state testing and steady state modeling from GT-Power. Engine technologies, such as turbochargers have a strong transient influence. One turbocharger technology may be better suited for transient cycles than others. Below is a figure showing the influence of an engine fuel map (2010 diesel engine) derived from different test cycle data and then applied to other test cycles. The steady state test cycle (RMC), showed an error of ~5% when applied to a hot cycle Federal Test Procedure (FTP) cycle and ~10% when applied to a hot cycle Federal Test Procedure (FTP) cycle. Did you do any transient test validation or have transient testing validation data?




**Nuszkowski, J.**, Shade, B., "The Impact of using Derived Fuel Consumption Maps to Predict Fuel Consumption," Directions in Engine-Efficiency and Emissions Research Conference (Detroit, Michigan), September 2010.

**2-3. Are the assumptions used in the analysis reasonable? Why or why not?**

There were many assumptions applied during the study and they seem reasonable. The most important assumptions (Tables 3.1 – 3.9) were the assumed reductions in drag, rolling resistance, chassis friction, and engine friction. Are these numbers based on references? The reader will assume these are achievable reductions.

**2-4. Are the findings and conclusions adequately supported by the data? Describe any findings or conclusions that are not sufficiently supported.**

The findings and conclusions are supported. Was there analysis (propagation of error) done on the model accuracy in regards to the influence in the percent error of the model to the percent error in the fuel consumption reduction? This may provide a guideline to what is considered a significant reduction in terms of percentage by your model.

**3. Evaluation of Testing and Simulation Approaches**

**3-1. Please comment on Section 4 of this report. Does this section adequately review, present, and summarize the available data relevant to: (1) fuel efficiency metrics that take vehicle work and use into account; (2) engine efficiency test procedures, vehicle efficiency test procedures (whole vehicle on-road, chassis dyno tests, etc.); and (3) efficiency simulation approaches? Describe any ways in which this section could be improved, as well as any additional key published data relevant to this review that should be included.**

This section gives a very good review of fuel efficiency metrics, test procedures, and simulation approaches. There wasn't any discussion on the accuracy of each method of testing and simulating. What could be the achievable accuracy of the different test methods and how significant does the change in the fuel efficiency metric need to be for chassis testing versus engine testing versus a test bench vs simulation? Accuracy was only briefly mentioned when discussing the measurement of accessories.

**4. General Comments**

**4-1. Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.**

Overall, the report was organized, readable, and clear with only minor corrections needed (see 4-4).

A table in the executive summary to summarize the results would be very beneficial to the report.

**4-2. Is the information provided in the report and appendices sufficiently detailed to thoroughly document all essential elements of the study? If not, what additional information is needed?**

The vehicle selection needs to not only be discussed in the executive summary. The longest discussion on vehicle selection was in the executive summary.

**4-3. What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?**

The wide breadth of vehicle and engine technologies analyzed on many different drive cycles was the strongest part of the report.

The weakest parts of the report were the minimum number of engine combustion technologies that were analyzed; minimal discussion on the influence of transient operation on these devices (especially the turbochargers) and model; and how worksite vocational trucks were represented. Include a lengthier discussion/analysis on engine combustion technologies. In addition, discuss each engine and vehicle technology's influence when operated on a transient cycle.

**4-4. Please provide any other comments you may have on this report.**

The factors that are to be considered for the report (page iii) included vehicle safety. I did not see any significant discussion on vehicle safety.

Some minor comments and corrections:

Throughout the document:

- replace the term “RPM” with “engine speed”
- Significant figures on benefits (percentages) need to be consistent.
- Combine one sentence paragraphs with other paragraphs
- Repeated text. Especially in the appendix. Can you just reference the earlier descriptions from other vehicles?
- Replace “&” with “and”
- Change “max” to “maximum” and ‘min” to “minimum”

Page iv to page v tables: The tables shown are arranged from largest engine size to smallest. The next table is smallest vehicle to largest. Please keep them in the same order.

Page 4 last paragraph: Fuel efficiency definition should be say “… inversely proportional to fuel economy” not “fuel consumption”

Page 9 end of first paragraph: “… 20205 timeframe” Is this number correct?

Page 13 links: Move the links to reference section

Page 16 last paragraph: “taday’s” should be “today’s”

Pages 19-24: weird spacing on references

Page 27 #4: change “avery” to “a very”

Page 27 #7: Mentioning of Daimler patent. Aren’t most technologies covered by a patent?

Page 30: A little too much pushy on HEDGE in this section.

Page 35 second paragraph from bottom: “the actual” is repeated

Table 3.13 and other similar tables: Remove the “%” symbol to make the numbers more readable

Page 40 second paragraph from the bottom: I think the references to Table 3.11 and Figure 3.1 are incorrect.

Page 41 second paragraph: change “…. 0.7% 1.5%” to include a dash

Page 46: The 10-spd manual results seem very high. Was there excessive shifting in the model?

Page 73 Table 3.21 versus Table 3.24: “V-6 to Base ISB” becomes “Base ISB vs. 3.5 V-6” The order is switched yet, the percentages are still the same”

Page 83 Figure 3.30: label of “EGR” is this “Stoich EGR”? Please be consistent with figure labeling.

Page 111 top of the page: "FPT" should be "FTP"

Page 111 last paragraph: "…..about right" change to "…approximately correct"

Page 111 figure label: "RamTechnologies" to "Ram Technologies"

Page A-1: Remove additional space on "1.5. Explore GDI …"

Page A-3: Figure labels needed

Page A-4 figure A 6: Why does the equivalence ratio map extend beyond the fuel map? Are you extrapolating data?

Page A-5 last paragraph: Remove additional paragraph space

Page A-9: Correct the labeling on the figure

Page A-14 very top: Only time an EGR mixer is mentioned. Did the other engines not need one?

Page A-25: Why is the EGR valve before the throttle here?

Page B-7: This is more validation figures than what was shown for the gasoline engines. Why?

Page B-13: The injection parameters would change between using an EGR and not using an EGR.

Page B-26 last paragraph: put spaces in "dowensizeenjoys"

Page B-28: bolding text in figure label

Page B-30: change "BEMP to "BMEP"

Page B-37: Was it mentioned in the text (and not in the appendix) that this engine model was created from a 2007 ISB engine?

Page B-51: Mention the specific "sanity checks" used instead of the term "sanity checks"?

Page C-14 last paragraph: change "… is huge" to "…is significant"

Page C-15 to C-16: table flows over onto next page

Page C-26: Figure C.9 label is on the next page

**5. Overall Recommendation**

**5-1. Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.**

(2) Acceptable with minor revisions. Please see Section 4 above for my revisions.