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Response to Peer Review Comments: Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study

Reports 1 and 2

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16. Abstract

This report documents the comments and suggestions of the peer reviewers for two technical reports on commercial medium- and heavy-duty truck fuel efficiency technologies. The authors of these reports separate the peer review comments and suggestions into discrete points, and then provide a response to each point along with a description of any changes made to the final report content.

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EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration (NHTSA) competitively awarded a contract to Southwest Research Institute (SwRI) to conduct research in support of the next phase of Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles. The research project produced two technical reports that underwent independent external peer review before final publication. These independent peer reviews were organized by a separate contractor, Eastern Research Group, Inc. (ERG), with six reviewers for each report. Report #1 completed the peer review process during the December 2014 to January 2015 timeframe, and all details of the peer review such as the selection and conduction process, reviewer's biographies, charge questions, and the raw comments received are documented in a final peer review report.[1] Report #2 completed the same peer review process in the May to June 2015 timeframe, and all details are documented in a second peer review report.[2]

The authors of the two reports separate the peer review comments and suggestions into discrete points, and then provide a response to each point along with a description of any changes made to the final report content. The information in this report is organized in a tabular format. Reviewer comments and suggestions are listed in the left hand column on each page. The report author's responses, and a description of any changes made to the final report text are provided in the right side column. **Bold text** in the left hand column represents either a question from the list of prompts provided to the peer reviewers, or it represents bold text used by the reviewers in their comments. **Bold text** in the right hand column represents changes (if any) that were made in response to reviewer comments. Standard text in the right hand column provides the author's explanation for any changes that were made.

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LIST OF ABBREVIATIONS AND ACRONYMS

6X2....................Tractor with a front axle, a drive axle, and a non-driven axle
6X4....................Tractor with a front axle and dual drive axles (tandem)
A/C....................Air Conditioning
AES...................Automatic Engine Shutdown
AFR...................Air/Fuel Ratio
ALVW………..Vehicle test weight for pickup trucks equal to the empty weight plus half of the payload that can go in the bed, with no trailer
AMT..................Automated Manual Transmission
APU...................Auxiliary Power Unit
BMEP................Brake Mean Effective Pressure (A unit to compare the relative load on engines of different size)
BSFC.................Brake Specific Fuel Consumption
BTE...................Brake Thermal Efficiency
CAFE ....Corporate Average Fuel Economy
CARB................California Air Resources Board
Cd......................Coefficient of Drag (Aerodynamic drag)
CFD...................Computational Fluid Dynamics
CH_4....................Methane
CILCC...............Combined International Local and Commuter Cycle
CNG..................Compressed Natural Gas
CO.....................Carbon Monoxide
CO_2....................Carbon Dioxide
Crr.....................Coefficient of Rolling Resistance (Tire rolling resistance)
DD15.................Detroit 15 liter heavy duty truck engine (formerly Detroit Diesel)
DEF...................Diesel Exhaust Fluid (Urea mixture used in SCR catalysts)
DPF...................Diesel Particulate Filter
E10....................Gasoline with 10% ethanol content
ECM..................Engine Control Module
EGR...................Exhaust Gas Recirculation
EPA...................United States Environmental Protection Agency
EVO..................Exhaust Valve Opening (Valve timing)
F-650.................Ford Class 5 and 6 truck model
FMEP................Friction Mean Effective Pressure (Unit for comparison of friction between different engines)
GDI...................Gasoline Direct Injection
GEM.................Greenhouse gas Emissions Model (EPA tool for determining compliance with truck GHG regulations)
GCW.................Gross Combination Weight (Weight of the vehicle and trailer combined)
GHG..................Greenhouse Gas (CO_2, N_2O, CH_4, and others. In this report, CO_2 is the focus)
GT-POWER......Commercial 1-dimensional engine simulation code. Part of GT-SUITE.
GVW.................Gross Vehicle Weight
GVWR..............Gross Vehicle Weight Rating (Vehicle mass with maximum allowed payload)
HCCI.................Homogeneous Charge Compression Ignition

LIST OF ABBREVIATIONS AND ACRYONYMS (CONT'D)

HD .... Heavy Duty (Typically refers to Class 8 trucks with engine of 10 liters or more displacement)
HPCR .... High Pressure Common Rail (Diesel fuel system)
HPDI .... High Pressure Direct Injection (Natural gas is directly injected into the cylinder, followed by a diesel pilot injection that serves to ignite the gas)
ICCT .... International Council on Clean Transportation
IEA .... International Energy Agency
ISB .... Cummins 6.7 liter diesel engine (also available as a 4.5 liter 4-cylinder)
IVC .... Intake Valve Closing (Valve timing)
LD .... Light Duty (Typically refers to Class 2b and 3 trucks. Note that to passenger car manufacturers, Class 2b and 3 are called "Heavy Duty". This leads to considerable confusion between people with car and truck backgrounds.
LNG .... Liquefied Natural Gas
LTC .... Low Temperature Combustion
MD .... Medium Duty (Typically refers to Class 4 through "Baby 8" trucks with engine displacements below 10 liters)
mm .... millimeter
MY .... Model Year
N_2 .... Nitrogen
N_2O .... Nitrous Oxide
NOx .... Nitrogen Oxides
NAS .... National Academy of Science
NESCCAF .... Northeast States Center for a Clean Air Future
NH_3 .... Ammonia
NHTSA .... National Highway Traffic Safety Administration (Responsible for fuel economy regulations)
NREL .... National Renewable Energy Laboratory
NMHC .... Non-Methane Hydrocarbons
NO .... Nitric Oxide
NO_2 .... Nitrogen Dioxide
NOX .... Oxides of Nitrogen
O_2 .... Oxygen
DOC .... Diesel Oxidation Catalyst
ppm .... Parts per Million
PFI .... Port Fuel Injection
PM .... Particulate Matter
RCCI .... Reactivity Controlled Compression Ignition
rpm .... revolutions per minute
SCR .... Selective Catalytic Reduction
SwRI .... Southwest Research Institute
T270 .... Kenworth Class 6 truck model
T700 .... Kenworth Class 8 long haul tractor model
TCPD .... Turbocompound
VIUS .... Census Bureau Vehicle Inventory and Use Survey
VMT .... Vehicle Miles Traveled (per year)
VSL .... Vehicle Speed Limiter (also called road speed governor)

LIST OF ABBREVIATIONS AND ACRYONYMS (CONT'D)

VVA .... Variable Valve Actuation (Variable lift and duration)
VVT .... Variable Valve Timing (Typically cam phasing, but constant lift and duration)
WHR .... Waste Heat Recovery
WHSC .... World Harmonized Steady-State Cycle (An engine dyno test cycle)
WHTC .... World Harmonized Transient Cycle (An engine dyno test cycle)
WHVC .... World Harmonized Vehicle Cycle (Truck test cycle with urban, rural, and motorway segments)

Final Report #1
Dana Lowell Reviewer Comments and Responses

Comment	Response
1.1 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	**No response required**
1.1 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	The literature review was completed in 2012 with the goal of informing the simulation modeling, and new additions were only made in areas related to the scope of the work completed in this study. **No change to the text**
1.2 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)	**This reference was added**
1.2 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?	**Text expanded in the Executive Summary to explain the six market segments in more detail.**
1.2 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	This data would be very useful, but it is not available. Acquiring the data is outside of the project scope, so **no change to the text**
1.3 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.	No information was found regarding Mexico or Brazil. We recently learned that Mexico plans to start considering regulations in late 2015. **A new section of text was added to cover the EU**, which is only planning a fuel consumption labeling requirement at this time

Comment	Response
1.3 It would be helpful to the reader to include a table that briefly summarizes current and future regulatory approaches in each country/region.	Because each country is taking a different approach and using different metrics, we were not able to create a useful table. **No change to the text**
1.2 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.	**No change required**
1.2 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.	The reviewer correctly understands our intent. The tow truck was included because it helps flesh out the vocational vehicle classes, and because calibration data was available from an EPA project. **New text added in the first paragraph of section 3.0 to add clarification**
1.2 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.	Data on the power demand and efficiency of PTO driven equipment would be very useful, but was not available in the literature. Acquiring this information was beyond the project scope. **No change to the text**

Comment	Response
1.2 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.	**No change required**
2.1 The methodology used to evaluate the chosen engine and vehicle technologies was appropriate to the aims of the project, and was clearly described.	**No change required**
2.1 The methodology used to evaluate the chosen engine and vehicle technologies was comprehensive and robust enough to provide credible results	**No change required**
2.1 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.	There is an almost infinite range of vehicle types and drive cycles. Some identical vehicles experience very different drive cycles, depending on how they are employed. The cycles used in this project were selected by SwRI with EPA, NHTSA, and CARB input, in an effort to be broadly representative. Several cycles can't be fit into any one specific vehicle category. **No change required**
2.1 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.	**Drive cycle descriptions have been added to Appendix C**
2.2 The models used were appropriate for the analysis and appear to have been correctly applied	**No change required**
2.3 The assumptions used in the analysis appear to be reasonable	**No change required**
2.4 The findings and conclusions are adequately supported by the data.	**No change required**
3.1 This section [4] adequately reviews, summarizes and presents available data on fuel efficiency metrics	**No change required**

Comment	Response
3.1 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.	**New paragraph added to address this comment in 4.2.1.**
3.1 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.	**Two lines added to the first paragraph of 4.4.3.** to express the value of keeping criteria emissions cycles and fuel economy cycles common.

Comment	Response
3.1 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.	**New line added at the end of 4.5.1 to describe the potential limitations of the current GEM model. However, recommendations for how GEM could be modified were beyond the scope of the study.**
4.1 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)	**Table added in Executive Summary**
4.1 Otherwise I believe that the report is well organized, clear, and readable. I do not believe any major changes are required.	**No change required**
4.2 The report and appendixes are very detailed and they thoroughly document the methodology and results of the study.	**No change required**
4.2 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: [repeat of comments shown above]	The list of additions is a repeat of those described above. **No additional changes required**
4.3 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.	**No change required**
4.3 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	**Changes already addressed above**

Comment	Response
4.4 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.	**New lines added in Section 3.0 comparing diesel and gasoline for energy content and CO_2**
4.4 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	**Error corrected in text.**
5.1 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.	**Changes described above.**

Final Report #1
Shawn Midlam-Mohler Reviewer Comments and Responses

Comment	Response
1.1 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.	**New text added in Literature Review.**
1.1 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.	**New text added in Literature Review.**
1.1 There is no specific discussion of the European Union in this section of the document in regards to fuel economy regulations.	At the time of the literature review, there was no regulatory activity in Europe. **Because of its importance, Section 4.3.3 has been added to cover European regulatory activity.**
1.1 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.	**No change required**
1.2 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.	The literature review was conducted by several individuals, each working his field of expertise. As a result, there was not a common approach between topics. Redoing the literature review with a common, pre-defined approach is out of the project scope. **No change to the text.**

Comment	Response
1.2 In terms of technologies, I feel that the list serves as a suitable basis for the analysis.	**No change required**
1.2 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.	**New text added in sections 2.3.2.1, 2.3.2.5, 2.3.2.6, and 2.3.2.7**
2.1 The approach used is credible as it explores a wide range of drive conditions and vehicle states (payload.)	**No change required**
2.1 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 authors agree that a sensitivity analysis on model calibration errors would be useful, but the project time and resources did not allow for it. **No change to the text.**
2.1 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.	**An overall summary section has been added (Section 5).**
2.2 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.	**No change required**

Comment	Response
2.3 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.	The reviewer may have misread this section. The six experimentally measured parameters were not used to calibrate the model – they were used as direct inputs to the model. On Page A-3, a total of 17 parameters are listed that were used to validate the GT model against experimental data. **No change required**
2.3 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.	**New text added on page A-15**
2.3 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.	**New text added at the bottom of page A-17, and on A-18**
2.3 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.	**No change required**

Comment	Response
2.3 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.)	**New text added on page A-24**
2.3 The approach used in section 2.6 (A-25) requires the same type of justification.	**New text added on page A-33**
2.3 The approach used in Appendix section 2.4 and 2.5 appears sound given the constraints of the study.	**No change required**
2.3 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.	The 10% FMEP reduction value was taken from the literature on gasoline engine friction reduction. References ET-1, ET-2, ET-11, ET-13, ET-17, and ET-19 were considered in determining this value. No specific feature list was created. **No change required**
2.3 Figure quality in B1a and B1b (B-4) is poor	**Font sizes increased in Fig. B1a.** Figure B1b is limited by fixed output limits in GT-Power.
2.3 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.	Air flow agreement is shown in the plot at the top of page A-6. **New text added just above Figure B1c.**

Comment	Response
2.3 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.	**No change required**
2.4 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.	**Changes described above**
3.1 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	Given that the regulatory changes in many countries are still under development, it is not possible to compare them fully. **No change to the text**
3.1 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	GT-POWER is widely used and well known in the industry for engine simulation. GEM is an application for simulating vehicle compliance to a known set of standards. The in-house vehicle simulation code used for this project has far more capability than GEM, and could be compared to GT-DRIVE. **No change to the text**
3.1 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.	**No change required**
4.1 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.	**No change required**

Comment	Response
4.2 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.	**No change required**
4.3 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.	**No change required**
4.3 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.	This would make a good report topic, but is beyond the project scope. **No change to the text**
5.1 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.	**Changes described above**

Final Report #1
William de Ojeda Reviewer Comments and Responses

Comment	Response
1.1 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.	**No change required**
1.1 This section may be improved by indicating the relative success or the acceptance of these technologies onto OEM products.	**Added Section 2.5, which refers to reports published by NACFE on market acceptance and technology performance in field operation**
1.1 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*).	**Added material on Miller cycle, asymmetric turbochargers, and VVA (throttle-free operation)**
1.1 The **Vehicle Technologies** section (2.4) is also very concise across the technologies reviewed, with few representative references quoted. Review of these references fails 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."	Summarizing the findings of all papers would require an extensive expansion of the literature review. The descriptions provided are adequate to allow the reader to decide if the paper is of interest. **No change to the text**

Comment	Response
1.2 This [market segmentation] appears to be the area addressed in Specific Requirement (SR 3), which according to the statement on top of page 3, was not completed.	**The introduction was revised to remove references to SR numbers, and to delete references to tasks that were removed from the project scope. The report now only references the work completed.**
1.2 Only brief references to market segmentations are given in the text.	**Discussion of market segmentation has been expanded.**
1.2 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.	**Added Section 2.5, which refers to reports published by NACFE on market acceptance and technology performance in field operation.** Additional study or surveys are out of the scope of this project.
1.2 This reviewer finds the review of fuel economy regulations very weak.	**Fuel economy regulations section expanded, description of EU approach added.**
1.2 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	The Phase 1 regulations are complex, with many targets by vehicle and engine type, so a summary table was not added. **A line was added in 2.2.1, referring to the discussion of regulatory approaches in section 4.3.** Data to meet suggestions b, c, and d is not available.

Comment	Response
1.2 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.	**Added a paragraph describing the difficulties in comparing different country's regulations, and added description of the Japanese standards.**
1.2 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.	**Added Section 2.5, describing the NACFE reports that are now available.**
1.2 Page 7 insert "of refeference [R-7]" in sentence *Pages 23 through 28 "of reference [R-7]" discuss …*	**Typo fixed.**
1.2 Page 9: "viable in the 20~~10~~5 time frame"	**Typo fixed.**
1.2 Page 9: "de ~~Ojeta~~ [Ojeda] reports"	**Typo fixed.**
1.2 Finish sentence on page 9: "eclectic power, ~~then~~ [whereupon it is] re-condensed [prior to pumping it again into the boiler unit]."	**Typo fixed.**
1.2 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]"*.	**Wording revised to avoid confusion**
1.2 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.	**The water pump discussion was moved from 2.3.5.1 to 2.3.5**
1.2 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.	**No change required**

Comment	Response
2.1 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 on the one hand 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.)	Due to the low market penetration of alternative fuels, and a lack of experimental data to calibrate the models, alternative fuels were beyond the project scope. **Text added in the 3rd paragraph of section 3.0 to explain.**
2.1 The process is adequate. The criteria for evaluation is the percent in fuel efficiency improvement.	**No change required**
2.2 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.	The units used in our report (% fuel saved) translate directly to % reductions in grams of emissions or gallons per ton-mile fuel consumption. **Text added in section 3.3**
2.2 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.	**New summary section 5 added.**

<table>
<tr><th>Comment</th><th>Response</th></tr>
<tr><td>2.2 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.</td><td>No change required</td></tr>
<tr><td>2.2 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:
<table>
<tr><td>Class</td><td>Vehicle</td><td>Diesel</td><td>Gasoline</td></tr>
<tr><td>2a</td><td></td><td></td><td></td></tr>
<tr><td>2b</td><td rowspan="2">Ram Pick-up</td><td rowspan="2">6.7 385HP
4.5L model</td><td rowspan="2">3.5L V6
6.2L V8</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>T270 BOX
F-650 Tow Truck</td><td>6.7L 300HP</td><td>3.5L V6
6.2L V8</td></tr>
<tr><td>7</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>T700</td><td>DD15
12.3L model</td><td></td></tr>
</table></td><td>New tables and text added in Section 3</td></tr>
<tr><td>2.2 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.</td><td>References to the 8.9 liter diesel have been removed</td></tr>
<tr><td>4.1 Quality of the report is regarded as high</td><td>No change required</td></tr>
<tr><td>4.3 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.</td><td>No change required</td></tr>
</table>

Comment	Response
4.3 Weak points: • The number of cycles used adds 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.	No numerical output will be removed. Determining which technologies are most likely to be applied beyond 2019 is beyond the project scope. A separate cost report has been provided, and the cost information will be used by the agencies to evaluate cost/benefit. **Text added at the end of Section 3.2 to describe the weight impact of certain technologies, and how this can hurt freight efficiency.**
4.4 **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.	**No change required**
4.4 **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.	**No change required**
4.4 Page 35: "Appendix D… cannot provide the actual ~~the actual~~ input data used in the simulation runs."	**Typo fixed**
4.4 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.)	**Appendix A revised to include comparison of 3.5 V-6 simulation results to experimental data.** The V-8 model is proprietary, so comparison data cannot be provided.
4.4 Yes, the results are in line with former studies (such as the NESCCAF 2009 report).	**No change required**

Comment	Response
4.4 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.	**New Section 5 added.**
4.4 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.	**No change required**
4.4 <u>On the engine side</u>, 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%) .	**No change required**
4.4 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.	**No change required**
4.4 <u>On the Vehicle side</u>, 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.	**No change required**
4.4 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.	**No change required**

Comment	Response
2.3 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 to assess 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.	**No change required**

Comment	Response
2.3 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.	These are good points about aftertreatment heat management and fuel penalties, but there is very little information in the literature on the fuel penalties associated with aftertreatment. **A paragraph was added at the end of Section 3.2 describing the heat management / fuel consumption issue. Another paragraph was added in Section 3.2 to describe the weight issues caused by aftertreatment and efficiency technologies.**
2.3 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.	**New paragraph added at the end of Section 3.0**
2.2 The authors could have included turbo-charger **VNT technology**, though this may have been "inserted" under Technology 12 – higher efficiency turbo.	VNT turbocharger maps were not made available to the authors. **An explanation was added in Appendix B.**
2.4 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?	When the power turbine and EGR systems are removed, pumping work is reduced, but the power contributed by the power turbine is lost. At part load, the net trade-off is positive. At full load, there is a slight penalty. **New text added in Appendix B, section 1.7**

Comment	Response
2.4 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.	**New text and table added in Appendix C, section C2.3**
2.4 Little discussion is given to **weight of the technologies** (e.g. in the waste heat recovery), where as **freight efficiency** should have been addressed.	**Paragraph added in Section 3.2.** Also, there is existing text on this topic in Section 3.3.1.20
2.4 Page 48: *These results are shown in Figure ~~3.6~~ 3.7 below.*	**Typo fixed**
2.4 Page B-14, B-16, B-18, B-22, B-36: GROSS IMEP on figures should read PMEP.	**Typo fixed**
2.4 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.	This was actually done, but was not reported in the draft report. **New Section 1.15 added to Appendix B covering Diesel VVA**
2.4 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?	**3.5 V-6 validation added to Appendix A**
2.4 *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.	**New Table 3.2 added in Section 3.0**
2.4 *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?	This information would be useful, but it is beyond the project scope. **No change to the text**
2.4 *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 assess the relative contributions of the following technology additions.	**Suggested change made (table number is now 3.19)**
2.4 *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.	**New text added in Section 3.3.3.4**

Comment	Response
2.4 *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?	This information would be useful, but would require creating new fuel maps, and so is out of the project scope. **No change to the text.**
2.4 *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.	**Description of temperatures and limits added to Appendix A, section 1.4**
2.4 *Section 3.3.3.10:* What is the effect of added EGR on combustion efficiency and would this affect the efficiency numbers presented here?	EGR results in slower heat release, which has a negative effect on efficiency. **Line added in 3.3.3.10**
2.4 *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.	**Additional information and a reference added in Appendix A, Section 2.2.**
2.4 *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?	**New text added in Section 3.3.4.2**
2.4 Page 61: "in this case, 600 to ~~6,000~~ 5,500RPM". [Data in appendix reports 5,500rpm for the V6 engine).	**Typo corrected**
2.4 CLASS 6 F-650 Truck: 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.	This recommendation was applied to Final Report #2. **No change to the text**
2.4 *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.	These paragraphs are redundant, but were retained to allow each section to stand alone. **No change to the text**
2.4 *Figure 3.24* shows the Y-axes and title overlapping. Please correct.	**Figure modified**
2.4 CLASS 2b-3 Trucks - Ram Pickup Truck: This section too follows closely the CLASS 6 sections.	Some paragraphs are redundant, but were retained to allow each section to stand on its own. **No change to the text**

Comment	Response
2.4 *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.	**Text modified to improve clarity**
2.4 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.	**Text modified to improve clarity**
3.1 TRADEOFF BETWEEN FUEL CONSUMPTION AND NOx: 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.	Data on aftertreatment fuel use is not available, but **text was added at the end of Section 3.2 describing the issue.** Evaluation of medium duty NOx / BSFC trade-off was beyond the project scope. **No change to the text.** **Text added in 2nd paragraph of Section 3.4** **New text added below Figure 3.34**
4.1 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.	**No change required**
4.1 The report however does not provide conclusions or 'final remarks'.	**New Section 5 added**

Comment	Response
4.1 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>.[underestimated?] - 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.	**No change required**
4.2 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.	**New Section 5 added**
3.1 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).	A table summarizing all of the required values would be very large, and references are available with all the requirements. **No change to the text**
3.1 The discussion [on metrics] 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).	**No change required**
3.1 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.	**No change required**

Comment	Response
3.1 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.	**Reference added**
3.1 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.	**No change required**
3.1 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.	Properly addressing this comment would require an extensive review of the off-cycle credit process, which is beyond the project scope. **No change to the text.**
3.1 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.	**No change required**
3.1 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.)	**New text added in 3rd paragraph of Section 4.3.3**
3.1 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.	**No change required**

Comment	Response
3.1 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.	**Added a line above Figure 4.4 stating that no additional public domain data was available**
3.1 One [thought] 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.	This suggestion is beyond the project scope. **No change to the text**
3.1 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 CO_2/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).	This suggestion is beyond the project scope. **No change to the text**
3.1 Page 98, * CFD analysis, or [Constant speed testing]	**Typo corrected**
3.1 Page 98, • ~~Constant speed testing~~ Steer…	**Typo corrected**
3.1 Page 100, routes where smart ~~of~~ [or] GPS-based cruise control	**Typo corrected**
3.1 Page 102, Section ~~7.2~~ 4.2	**Typo corrected**
3.1 Page 103, Section ~~7.2~~ 4.2	**Typo corrected**
3.1 Page 105, were evaluated in Section ~~5~~ 4.2.2	**Typo corrected**
3.1 Page 111, the ~~FPT~~ FTP cycle clearly over-represents	**Typo corrected**
4.1 Organization: The organization follows a logical 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 and simulation approaches, and recommendations for tractor-trailer and vocational vehicles.	**No change required**
4.1 Readability and clarity: The report reads well. The more technical discussions are added in the appendices, which are well documented.	**No change required**
4.1 The report needs a Conclusion Section (different than the Executive Summary).	**Section 5 added**

Comment	Response
4.2 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.	Font sizes on many figures cannot be changed. **No change to the text** This is done in accordance with the SwRI report format standard. **No change to the text**
4.2 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.	This is described in the text just below the table. **No change to the text** **Clarification added** **Clarification added** After review, it was decided to retain the existing text. Adding full backup to the descriptive sentences would greatly increase the size of the report. **No change to the text**
4.1 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.	**No change required**

Comment	Response
4.2 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.	Data not available **– No change** No specific hardware recipe, but **technology menu added to Appendix C, sections C2.2, C2.3, and C2.4** No specific hardware recipe, but **technology menu added to Appendix C, sections C2.2, C2.3, and C2.4** Data not available **– No change**
4.3 [Report] 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.	**No change required**

Comment	Response
4.3 [Report] 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;	Engine simulation was intentionally more detailed than vehicle simulation. **New paragraph added above Fig. 3.1 added to explain**
- 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;	**Line added to clarify that results are all in terms of fuel consumption (gallons per 100 miles), not fuel economy (mpg).** Information is not available to put all results in terms of gallons per 1000 ton-miles
- There is little consideration to weight and packaging of components, with special mention to implications in freight efficiency;	**New discussion added in Section 3.2**
- There is no cost-benefit analysis such as "pay-back" period;	A separate cost report is part of the project. The agencies will conduct their own cost/benefit analysis. **No change to the text**
- 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;	This is beyond the project scope. **No change to the text Discussion of aftertreatment thermal management added to text**

Comment	Response
4.4 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.	Three levels of hybrid system are evaluated in Final Report #2. **No change required** **Discussion on natural gas added in Section 3.0** **Discussion on alternative fuels added in Section 3.0** **Discussion of dual fuels added in Section 3.0**
5.1 I find the report acceptable with minor revisions.	**Changes discussed above**
5.1 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.	**No change required**
5.1 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).	**New paragraph added above Table 3.1** to clarify that results are in fuel consumption, which is proportional to GHG and regulatory units

Comment	Response
7. The selection of 5 engine configurations (and three additional "modeled engine versions") appears adequate and well aligned to the selection of four vehicles.	**No change required**
3.1 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.	**No change required**
3.1 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.	**No change required**
3.1 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), revealing differences, though not as pronounced as with the Long-Haul vehicle data	**No change required**
1.1 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).	Because the regulations use different metrics that are hard to compare, a table is not feasible. **Discussion of the EU regulatory plans was added.**

Comment	Response
1.2 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:	
o 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);	**Addressed above**
o 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.	**Addressed above**
o 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,	**Addressed above**
o 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.	**Addressed above**
o A technology like Dual Fuel, in the sight of this reviewer, would be as competitive or more feasible than the Rankine waste heat recovery".	Data to evaluate this claim is not available. **No change to the text**
o 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.	**Addressed above**

<table>
<tr><th>Comment</th><th>Response</th></tr>
<tr><td>1.2 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.

<table>
<tr><th>Class</th><th>Vehicle</th><th>Diesel</th><th>Gasoline</th></tr>
<tr><td>2a</td><td></td><td></td><td></td></tr>
<tr><td>2b</td><td rowspan="2">Ram Pick-up</td><td rowspan="2">6.7 385HP
4.5L model</td><td rowspan="2">3.5L V6
6.2L V8</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>T270 BOX
F-650 Tow Truck</td><td>6.7L 300HP</td><td>3.5L V6
6.2L V8</td></tr>
<tr><td>7</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>T700</td><td>DD15
12.3L model</td><td></td></tr>
</table>
</td><td>Tables 3.1 and 3.2 added, with new text. References to the 8.9 liter engine removed.</td></tr>
<tr><td>5.1 The report should include a conclusion section. This should be different from the Executive Summary</td><td>New Section 5 added</td></tr>
</table>

Final Report #1

Matthew Barth Reviewer Comments and Responses

Comment	Response
1.1 Overall, the literature review provided in the report seems fairly complete. A few comments are provided below.	**No change required**
1.1 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.	No new references found. **No change to the text.** **Typo fixed** No post-2012 references added unless judged critical. **No change to the text.** There are no post-2002 references. The topic is discussed in more detail in Section 3.3.3.15. **No change to the text Moved to a new Section 2.3.5.3** **Modified description of reference R2** No post-2012 references added unless judged critical. **No change to the text** No post-2012 references added unless judged critical. **No change to the text**
1.1 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.	**No change required**

Comment	Response
1.1 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.	Decision was made to avoid criticizing the approaches of other governments (or of our own). **No change to the text.**
1.1 Strangely missing from the worldwide fuel regulation literature is what the European Commission is doing… This should be included in the report.	**Discussion of EU approach has been expanded and updated**
1.1 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.	SwRI was not tasked with redeveloping the regulatory drive cycles. Out of scope, so **no change to the text**
1.2 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?).	**New lines added to the first paragraph of Section 3.0**
• 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?	This is described in Appendix B. **No change to the text**
• Similarly, the selection of the representative gasoline engines seems appropriate based on what is most popular. Same statements as above apply.	**No change required**
• 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	**New 2nd paragraph of Section 3.0 added**

Comment	Response
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.	**New text added in Section 3.0**
2.1 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.	**No change required**
2.2 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.	**New text and references added to Appendix B**

Comment	Response
2.2 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?	**New paragraph added to Section 3.2**
2.2 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.	These are good suggestions, but beyond the project scope. **No change to the text**
2.2 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.	**New text added near Figure C.3 in Appendix C**

Comment	Response
2.2 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.	**Clarification added in Section 3.2**
2.3 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.	**No change required**
2.4 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.	**New section on VVA added in Appendix B** All information for 0%, 50%, and 100% payload is shown in Table 3.15. **No change to the figures** **New text added in Section 3.3.1.14** **New text added in Section 3.3.1.18**

Comment	Response
• 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".	All information for 0%, 50%, and 100% payload is shown in Table 3.16. **No change to the figures**
• 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?	**New text added in Section 3.3.2.4**
• 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…	**New text added in Section 3.3.2.7**
• 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.	Information for all payloads is provided in the tables. **No change to the figures**
• 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.	**New text added in Section 3.3.3.18**
• 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.	**Additional explanation added in Section 3.3.1.20**

Comment	Response
• 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.	**Text added in Section 3.3.1.21** **Text added to clarify that A/C power demand was treated as a steady load** **No change required** **The cycles where the vehicle was unable to follow the speed trace (US06 at full GCW) are marked in red in the table, with text to explain the issue** At the bottom of Page 91, potential future NOx standards are listed in the original text (0.05 and 0.02 g). We do not want to speculate about future standards, since the values and time frames are uncertain. **No change to the text.**
3.1 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	The focus of this project is to inform the next phase of standards, which are in the regulatory compliance space.

Comment	Response
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.	That goal is somewhat different from the study of real world performance that the commenter is seeking. This is out of scope, **so no change to the text**
• 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.	**Text modified to say "industry groups such as SAE"**
• 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.	**No change required**
• 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.	**No change required**
• 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.	By "optimize specifications for customer applications, we meant parameters such as engine rating, transmission type, axle ratio, weight reduction features, etc. Things like GPS-based cruise control get closer to what the reviewer is discussing. On the fly optimization is out of scope. **Text added to clarify meaning**
• Overall, there is very good coverage on the international standards work, in many ways, this covers the comments I made earlier.	**No change required**

Comment	Response
• 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.	**No change required**
4.1 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?	**No change required** Vehicle fuel and fuel additive effects are out of scope: only gasoline and diesel are considered. Driver feedback is also out of scope. References more recent than 2012 are not considered. Infrastructure has an important effect on real world fuel economy, but not on any regulatory certification cycle. **A paragraph was added to the introduction, describing these factors and stating that they are out of scope.** **Explanation added in 3.3.3.9** **Section 5 added**
4.2 Overall the information provided in the report is sufficiently detailed; various comments on specifics have been provided above.	**No change required**

Comment	Response
4.3 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.	All data is provided in the tables, so additional figures are not needed. **No change to the report**
4.4 Overall, good report and appendices	**No change required**
5.0 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	**Responses described above**

Final Report #1

Susan Nelson Reviewer Comments and Responses

Comment	Response
1.1 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.	**References added in Section 2.4.2.1**
1.1 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.	No new post-2012 references, unless critical to the report. **No change**

Comment	Response
1.1 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).	This was not added to the references, because it is post-2012, but **the NACFE reports were added in the main body of the report.**
1.1 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.	ATIS was not included in this project because of a lack of fleet survey data. Out of scope, so **no change to the text**

Comment	Response
1.1 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).	Data on potential benefits of this system was not available to implement in the simulations. Out of project scope, so **no change to the text.**
1.1 **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.	No new post-2012 references. **No change to the text**
1.1 **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.	No new references, but **new Section 4.3.4 on Canada regulations added**
1.1 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.	No new references, but **new Section 4.3.3 on EU regulations added**
1.2 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).	**No changes required**

Comment	Response
2.2 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.	**No changes required**
2.3 **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.	Crr data did come from coastdowns, and the results were arbitrarily split between tire rolling resistance and chassis friction, using historical SwRI spin loss data for axles and drivelines. **Extensive new text added to section C2.3**
2.3 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.	This is excellent background information, but out of scope. **No change to the text.**

Comment	Response
2.3 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.;	**New text added to Section C2.3**
2.3 2) laboratory measurements of Crr for the tires used on the study vehicles by tire type;	Not available. **Discussed in C2.3**
2.3 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	**New text added around Figure C3**
2.3 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).	This is the approach taken in the report. **No changes required**
2.3 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.”	Because coastdown data was used, the Crr values were not split into steer, drive, and trailer components. **Text revised in C2.3**
2.4 Elaboration of the derivation of Crr and supporting information should be provided as discussed in question 2-3.	**Text revised in C2.3**
2.4 A more thorough summary of vehicle simulation comparisons with chassis dynamometer data across the baseline vehicles would reinforce the credibility of Appendix C.	The suggested data is not available and out of scope. **No change**

Comment	Response
3.1 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.	**No change required**
3.1 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.	Including vehicle empty weight in the calculation of efficiency would eliminate empty weight reduction as a path to higher efficiency. There are alternative LSFC metrics such as gallons per cargo volume-mile that seem more appropriate. This discussion is out of scope, so **no change**
3.1 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.	**No change required**
3.1 **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	**No change required**

Comment	Response
3.1 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.	Regulatory strategy is out of scope. **No change required**
3.1 **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).	**New text added near new Table C.10**

<table>
<tr><th>Comment</th><th>Response</th></tr>
<tr><td>
<table>
<tr><th>Description</th><th>Steer Axle Weight, lb</th><th>Drive Tandem Weight, lb</th><th>Trailer Tandem Weight, lb</th></tr>
<tr><td>0% Payload case, Total vehicle weight 33960 lb.</td><td></td><td></td><td></td></tr>
<tr><td>Load distribution of empty tractor-trailer*</td><td>11000</td><td>15460</td><td>7500</td></tr>
<tr><td>% weight carried by axle or tandem</td><td>32%</td><td>46%</td><td>22%</td></tr>
<tr><td>Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)</td><td>6.5</td><td>6.6</td><td>5.1</td></tr>
<tr><td>Rolling resistance contribution of axle to Crr(veh), kg/T</td><td>2.11</td><td>3.00</td><td>1.13</td></tr>
<tr><td>Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T</td><td colspan="3">6.24</td></tr>
<tr><td>% Contribution of axle, tandem to total effective vehicle Crr(veh)</td><td>34%</td><td>48%</td><td>18%</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>100% Payload case, Total vehicle weight 80000 lb.</td><td></td><td></td><td></td></tr>
<tr><td>Load distribution of 46040-lb payload tractor-trailer</td><td>12000</td><td>34000</td><td>34000</td></tr>
<tr><td>% weight carried by axle or tandem</td><td>15%</td><td>43%</td><td>43%</td></tr>
<tr><td>Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)</td><td>6.5</td><td>6.6</td><td>5.1</td></tr>
<tr><td>Rolling resistance contribution of axle to Crr(veh), kg/T</td><td>0.98</td><td>2.81</td><td>2.17</td></tr>
<tr><td>Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T</td><td colspan="3">5.95</td></tr>
<tr><td>% Contribution of axle, tandem to total effective vehicle Crr(veh)</td><td>16%</td><td>47%</td><td>36%</td></tr>
</table>
* Assuming steer axle weight does not vary greatly due to engine weight on axle.
</td><td>Similar table added as Table C.10 in Appendix C</td></tr>
<tr><td>3.1 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.</td><td>Useful data on technology weights is not available for most technologies. Discussion added on the impact of technology weights</td></tr>
<tr><td>3.1 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.</td><td>New statement on this added at the end of Section 4.2.2</td></tr>
</table>

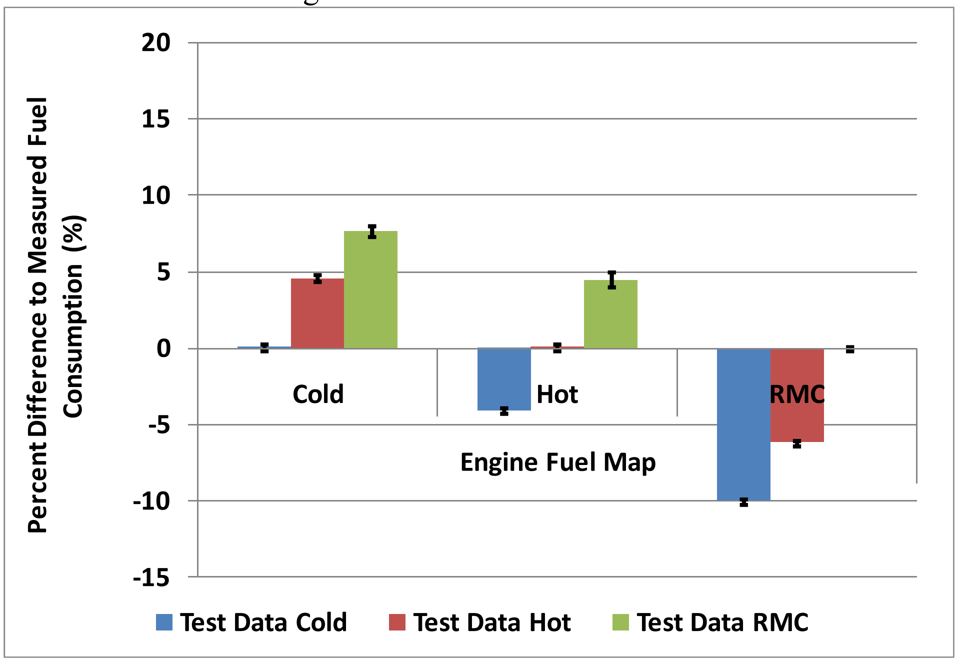
Comment	Response
4.1 Information content of the report is very dense. Detailed descriptions of performance results and the trade-offs associated with multiple technologies are often combined into the same paragraph, making it at times challenging to extract the most important points amid many comparative 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.	 **Some paragraphs broken up** **Some bullet lists added** **Several text changes** Impractical, because of incompatible units and approaches. **No change** **All references to SR numbers removed**
4.2 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.	**New text added near Figure C.3**
4.3 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	**No change required**
4.3 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?	**New paragraph added at the end of Section 4.2**
4.3 Are there recommendations of technologies that should move forward and others which should be abandoned?	This is left to the reader. **No change**
4.3 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.	**New text added near Figure C.3**

Comment	Response
4.3 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.	Market surveys are out of scope. **No change to the report**
4.4 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.	The 30% reduction in Crr is from the coastdown measurement baseline, not from the SmartWay baseline. **Section C2.3 revised to clarify this**
5.1 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.	These comments are addressed above. **No additional changes required**

Final Report #1
John Nuszkowski Reviewer Comments and Responses

Comment	Response
1.1 “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.	**New section 2.3.2.7 added on asymmetric turbos. New section added on stoichiometric EGR for gasoline engines**
1.1 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?	Yes. **New text added in 2.4.2.1 to clarify**
1.1 “market segmentation of fleets” This question is outside my area of expertise	**No change required**
1.1 “current and planned MD/HD fuel economy regulations in markets around the world?” This question is outside my area of expertise	**No change required**
1.2 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?	The comment about “no combustion technologies” applies only to diesel. **New and revised text added in Section 3.1.1**
1.2 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.	Adequate data to analyze work site vocational trucks is not available. Out of scope, so **no change**
1.2 The description of how the vehicles were selected was only included in the executive summary	**New text added to the Introduction**
1.2 The selected technologies gave a variety of options and analysis	**No change required**

Comment	Response
1.2 Many drivetrain options were investigated. Have you investigated the option of a continuously variable transmission (CVT) with high efficiency?	No indication was found that a CVT could match the efficiency of a manual or AMT. **New text added in Section 3.0**
1.2 Another interesting engine technology is having a variable compression ratio.	No production path identified yet. **New text added in 2nd paragraph of sec. 3.0**
2.1 The quality, scope, and rigor were definitely there. Models were extensively calibrated with experimental data when available.	**No change required**
2.1 The model was sufficiently described.	**No change required**

<table>
<tr><th>Comment</th><th>Response</th></tr>
<tr><td>2.2 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?

</td>
<td>The study relied on steady-state engine maps, and there is an error associated with this. The assumption is that the error does not change radically across the technologies evaluated, so the % fuel saved results should still be valid. A new paragraph is added in Section 3.2 to address this</td></tr>
<tr><td>2.3 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.</td>
<td>The numbers are based on a combination of references and engineering judgment. New text added in 3.3.2.2 and 3.3.2.3</td></tr>
<tr><td>2.4 The findings and conclusions are supported.</td>
<td>No change required</td></tr>
<tr><td>2.4 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.</td>
<td>Propagation of error analysis was out of scope. No change</td></tr>
</table>

Comment	Response
3.1 This section [4] gives a very good review of fuel efficiency metrics, test procedures, and simulation approaches.	**No change required**
3.1 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.	**Text added to describe the accuracy and sources of error in simulation**
4.1 Overall, the report was organized, readable, and clear with only minor corrections needed (see 4-4).	**No change required**
4.1 A table in the executive summary to summarize the results would be very beneficial to the report.	**New table added in Executive Summary**
4.2 The vehicle selection needs to not only be discussed in the executive summary. The longest discussion on vehicle selection was in the executive summary.	**New text added in the Introduction section**
4.3 The wide breadth of vehicle and engine technologies analyzed on many different drive cycles was the strongest part of the report.	**No change required**
4.3 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.	**New text added to address combustion technologies, transient operation, and vocational trucks.** Discussion of the effect of transients on every engine and vehicle technology is out of scope.
4.4 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.	**References to safety have been removed**
4.4 Some minor comments and corrections - Throughout the document: - replace the term "RPM" with "engine speed" - Significant figures on benefits (percentages) need to be consistent.	Style choice **– no change** Values below 10% are presented with one digit after the decimal, and values with two digits before the decimal point have no digit after the decimal point. **No change**

Comment	Response
- Combine one sentence paragraphs with other paragraphs	**Two single sentence paragraphs eliminated**
- Repeated text. Especially in the appendix. Can you just reference the earlier descriptions from other vehicles?	Decided not to force the reader to go back to earlier sections for explanation. **No change**
- Replace “&” with “and”	**Suggested edit made**
- Change “max” to “maximum” and ‘min” to “minimum”	**Suggested edit made**
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.	**Engine table on Page iv rearranged**
Page 4 last paragraph: Fuel efficiency definition should be say “… inversely proportional to fuel economy” not “fuel consumption”	**Suggested edit made**
Page 9 end of first paragraph: “… 20205 timeframe” Is this number correct?	**Error fixed**
Page 13 links: Move the links to reference section	These links are not numbered references, so they will stay in the text. **No change**
Page 16 last paragraph: “taday’s” should be “today’s”	**Error fixed**
Pages 19-24: weird spacing on references	**Error fixed**
Page 27 #4: change “avery” to “a very”	**Error fixed**
Page 27 #7: Mentioning of Daimler patent. Aren’t most technologies covered by a patent?	Most technologies discussed in the report can be implemented without patent issues, but the asymmetric turbo is

Comment	Response
	an exception. **No change to the text**
Page 30: A little too much pushy on HEDGE in this section.	**Several references to HEDGE removed**
Page 35 second paragraph from bottom: "the actual" is repeated	**Error fixed**
Table 3.13 and other similar tables: Remove the "%" symbol to make the numbers more readable	**Suggested edit made**
Page 40 second paragraph from the bottom: I think the references to Table 3.11 and Figure 3.1 are incorrect.	**Error fixed**
Page 41 second paragraph: change "…. 0.7% 1.5%" to include a dash	**Suggested edit made**
Page 46: The 10-spd manual results seem very high. Was there excessive shifting in the model?	These results are explained in Section 3.3.2.9. **No change required**
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"	**Error fixed**
Page 83 Figure 3.30: label of "EGR" is this "Stoich EGR"? Please be consistent with figure labeling.	**Label corrected**
Page 111 top of the page: "FPT" should be "FTP"	**Error fixed**
Page 111 last paragraph: "…..about right" change to "…approximately correct"	**Suggested edit made**
Page 111 figure label: "RamTechnologies" to "Ram Technologies"	**Suggested edit made**
Page A-1: Remove additional space on "1.5. Explore GDI …"	**Suggested edit made**
Page A-3: Figure labels needed	**Figure labels added**
Page A-4 figure A 6: Why does the equivalence ratio map extend beyond the fuel map? Are you extrapolating data?	**Plot corrected**

Comment	Response
Page A-5 last paragraph: Remove additional paragraph space	**Suggested edit made**
Page A-9: Correct the labeling on the figure	**Error fixed**
Page A-14 very top: Only time an EGR mixer is mentioned. Did the other engines not need one?	**Reference to mixer removed**
Page A-25: Why is the EGR valve before the throttle here?	The EGR valve is actually after the throttle (downstream). **No change to the text**
Page B-7: This is more validation figures than what was shown for the gasoline engines. Why?	**More validation figures added in Appendix A for 3.5 V-6**
Page B-13: The injection parameters would change between using an EGR and not using an EGR.	**New text added to 1st paragraph of B1.6**
Page B-26 last paragraph: put spaces in "dowensizeenjoys"	**Suggested edit made**
Page B-28: bolding text in figure label	**Suggested edit done**
Page B-30: change "BEMP to "BMEP"	**Suggested edit done**
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?	The origin of the engine model did not impact the simulations since the model was calibrated with data from a 2011 engine. **No change to the text**
Page B-51: Mention the specific "sanity checks" used instead of the term "sanity checks"?	**The term "sanity checks" removed, and check descriptions added to Appendix B**

Comment	Response
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	**Suggested edit made** **Suggested edit made** **Suggested edit made**
5.1 Overall recommendation: Acceptable with minor revisions. Please see Section 4 above for my revisions.	**Edits described above**

Final Report #2
Matthew Barth Reviewer Comments and Responses

Comment	Response
1.0 The executive summary does a reasonable job of summarizing the overall report, but it is chock full of a lot of acronyms and defined "packages" that the reader really won't know about until they read the actual report. As such, the executive summary does not really stand on its own. It reads more like a conclusion after you read the whole report, as opposed to an executive summary that would let a layman know the gist of the report. I'm not sure if that is under the purview of this review.	**Executive Summary replaced with shorter, more descriptive summary**
1.1 The introduction explains the "lay of the land" in terms of the NHTSA process and what the charge is leading to this report #3. It refers to report #1, in terms of updating the results and providing the relationship of this report #3 to the past report #1. However, there is very little mention of report #2 in the intro. Although we already know about Report #2 and what it is all about, a general reader of this report #3 might be wondering about it. A sentence describing it in the intro would help	**Reference to the cost analysis report added at the end of the 2nd paragraph of the introduction**
1.1 The intro (and section 3) discusses the "sweeps" it does of different parameters in the simulations. This term seems to be a bit of jargon, in academic papers we often describe these as a "parameter sensitivity analyses". I think simply stating that a "sweep" is essentially a "sensitivity analysis" would be useful, and then continue to call it sweeps after that.	**A reference to parameter sensitivity added at the bottom of Page 1 of the introduction, and in Section 2.3.6.1**
1.1 Overall, the intro of report #3 is sufficient to allow for report #3 be read as a stand-alone document.	**No change required**
1.2 Although it isn't crucial, the intro doesn't say anything about the conclusions of section 6, nor does it mention the contents of the appendices. The intro simply drops off abruptly right after describing section 6. A few more sentences might help here.	**Two paragraphs added to the introduction to describe Section 6 and the Appendices**
2.1 In section 2, it is stated that "NHTSA and SwRI agreed on combinations of technologies", but little or no detail is provided on how these combinations were chosen. It would be good to explain what were the guiding principles involved in terms of figuring out what combinations would be best, or most likely. The choice of the combinations of technology is a very important step and very little is said about it. The reader is left wondering if there are other combinations that maybe made sense, and deserved some analysis.	**New text added to the first paragraph of Section 2.1**

Comment	Response
2.1 In the technology combinations, there are a lot of acronyms, which is fine, since they are defined in the acronym list early in the report. However, the authors I think abbreviate previous packages (e.g., P1, and P2) but the reader isn't exactly clear if this is the case. It would be good to simply say what is meant by P1, P2, etc…	**Package number abbreviations added to Tables 2.1 through 2.9. Changed abbreviation of vehicle packages to VP1 – VP20 to avoid confusion. Fixed package references in Section 2.3.6**
2.1 It is understood that the main purpose of this effort is to evaluate fuel economy improvements and reductions of GHG emissions. As such, GT-POWER and the associated simulation tools are sufficient to make a good determination, given the different assumptions that are made along the way. However, there is very little discussion on the tradeoffs between control of pollutant emissions and fuel economy savings. In addition to the fuel economy improvement rules by NHTSA, vehicle and engine manufacturers must also comply with pollutant emission regulations. GT-POWER and the associated simulation tools do not examine the pollutant side of the equation, so there is a bit of a concern that by implementing certain technologies (or combinations of technology) for fuel economy, what would the effect be on pollutant emissions? Combined fuel economy and pollutant emissions analysis would be more appropriate. But it seems that this is outside of the scope of the project.	**Added reference to the emissions vs. fuel consumption trade-off discussion in Report #1 in Section 2.1**
2.1 In terms of drive cycles, I think report #1 discusses how these certain cycles were selected, based on providing a good range of operations for the different vehicle types. However for simulation analysis, an interesting 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.	This is an excellent suggestion for a future project, but out of scope for this project. **No change to the text**

Comment	Response
2.1 It is possible for the reader to determine which technologies provide additive benefits, which combinations do not, etc., by examining the data (tables and graphs). There is some commentary about the different combinations, but the report could be improved if a paragraph was inserted after each vehicle type (DD15, T700, etc.) that explicitly stated what technologies were additive, which combinations did not work well, etc. The descriptions provided only touch on specific combinations; but there isn't any analysis that talks about how the different combinations compare. (actually, this is done more so for the later vehicles types, e.g., F-650, etc., but not so much for the initial vehicle types)	**New sections added: 2.3.2.13, 2.3.3.6, 2.3.5.12, and 2.3.5.18**
2.1 On page 19, there is a reference to the SuperTruck program, but little info is given. A reference should be provided…	**Two references added**
2.1 Minor issue: the figure 2.6 has the black baseline line at 1% rather than at 0%, not sure if that is a graphical problem or if that was done on purpose?	**Error corrected**
2.1 Minor: on page 40, not sure why "Vehicle Technology Combinations" is capitalized;	**Capitalization eliminated**
2.1 In table 2.20 on page 44, it isn't clear why the "2019 ISB" is in there twice. Isn't this the baseline that things are being compared to? Or is this the diesel comparison? This needs a bit more explanation in the text, it is confusing to the reader.	**New text added just above Table 2.20**
2.1 For figures 2.23 and 2.24, why is the scale of the graph chosen to be 20%, when all of the percent savings are around 12% or less? The other graphs had better scaling, these figures seem different.	**Figure rescaled to 14% full scale**
2.1 Section 2.3.11 seems to be missing text that interprets the results of table 2.23. The different percent FC benefits are in the data, but there should be some text that interprets this. It would also be interesting to compare this to the other technologies discussed so far in the report.	**New paragraph added in Section 2.3.11 to interpret hybrid results**
2.1 Overall, the methodology described in section 2 is for the most part clearly described and appropriate, with some caveats as described above. The results are sufficiently comprehensive and robust.	**No change required**
2.2 Overall, the technologies selected were appropriate and logical for the vehicle. As mentioned above, it was difficult to determine how these combinations were selected in the first place; it seems that they were selected by NHTSA and SwRI in an ad-hoc fashion. Nevertheless, they seem appropriate.	**New text added to the first paragraph of Section 2.1**
2.2 It would be interesting to see some combinations of the hybrid technology (e.g., integrated starter/generator) with the other standard FC savings measures.	Good idea, but out of scope. **No change to the text**
2.3 Yes, the vehicles and drive cycles were appropriate for this class of vehicles (see earlier comment about driving cycles)	**No change required**

Comment	Response
2.4 Yes, the computer models were appropriate for the analysis. Although many assumptions were made, they all seemed logical. The modeling results provided reasonable numbers and are very good for relative comparisons.	**No change required**
2.5 Yes, the assumptions are all reasonable.	**No change required**
2.6 In general, the conclusions are adequately supported by the data. However, this section needs a good wrap-up set of paragraphs that talks about the different results at a higher level. For example, how did all of the technology combinations compare across different vehicle platforms? What might be other technology combinations that were not explored? (e.g., the inclusion of mild hybridization with other standard FC saving technology).	**One paragraph added to Section 6.1, and 3 paragraphs added at the end of Section 6.4**
3.1 I'm not sure why Figure 3.1 only shows the Cd values of 5% and 10%, where the other figures showed 5%, 10%, and 15%. Why was 15% left out?	**Explanation added below Figure 3.3**
3.1 The general conclusions of aerodynamics are logical, the main effect occurs at higher and sustained speeds.	**No change required**
3.1 On page 62, the sentence "The large frontal area of the T270 limits the portion of road load that comes from tire rolling resistance" needs more explanation… how does the frontal area limit the rolling resistance road load?	**Last paragraph of Section 3.2 revised**
3.1 For rolling resistance reductions, it should be mentioned that there might be other important less desirable implications such as lower traction, load distribution, etc.	**New text and 2 new references added**
3.1 For the weight reduction, it is unclear how the different weight reduction values were chosen for the different vehicle types. The RAM pickup was studied at 300, 600, and 900 lbs. The F-650 was studied at 400, 700, and 1000 lbs. The T-270 was studied at 400, 800, 1200 lbs. Were these chosen based on a general percentage of the vehicle's overall weight?	**New text added to 1st paragraph of Section 3.3**
3.1 It seems that the section on axle ratios (sections 3.4, 3.5, 3.6) has a lot more detail than the other parameters sensitivity analyses; although it is interesting, I'm not sure if it adds a lot to the report. As mentioned, you design a vehicle to meet certain performance specifications, and then you do what you can get improved fuel economy without affecting those performance specifications.	**No change required**
3.2 Yes, the ranges are appropriate for all 4 different parameters	**No change required**
3.3 **Were the vehicles and engines used in the parameters sweeps appropriate?** Yes	**No change required**
3.4 Yes, the results are plausible.	**No change required**

Comment	Response
4.2 Section 4 is an interesting section, describing differences of different engine technologies and relative payoffs between diesel engines and gasoline engines with technologies.	**No change required**
4.2 In the cost analysis on page 80, it is unclear how the authors came up with the assumption that the average engine cost difference was $9000. Earlier the report stated that emission control technology on diesels are a major part of the expense. However, very little is mentioned on the cost of the future FC savings technology that would be put on gasoline engines (e.g., package 16 and package 20 technology elements). Is that cost part of the $9000 difference assumption? I guess report #2 specified that cost elements of the different fuel savings technology. This report #3 should refer to this.	**New text added above Table 4.2**
4.2 Sections 4.2, 4.3, and 4.4 are all interesting, but somewhat disjointed. For section 4.4, it seems you could apply a driving cycle with a lot of stops and idle to calculate how much you could save with stop/start technology.	Good suggestion, and the Parcel cycle would make an ideal test case. Out of scope, so **no change**
5.2 Overall, this is a well written section on the issues of natural gas. The authors hit on all the key topics areas (and the tradeoffs), including engine and vehicle availability, size and weight penalties, engine, fuel, and vehicle prices, fuel availability, and government incentives. It is fairly complete, but it seems that the authors mainly discuss the general disadvantages of natural gas solutions, emphasizing less on the positives (better energy independence, lower GHG, etc.). The transit industry has successful used natural gas in their fleets, overcoming many of the points outlined in this section. I wonder if the authors could discuss a bit more on how it has been successful for transit, but may not be for the vocational trucks.	**New text added in the 1st paragraph of Section 5**
5.2 Minor: on page 84, the hyphen of "-260 degrees" is on one line and 260 on the next, making it confusing what the temperature is.	**Error corrected**
5.2 On page 84, the sentence "A slow fill happens at nearly constant temperature, so a loss in energy density does not occur" would be more correct if stated: "A slow fill happens at nearly constant temperature, so a loss in energy capacity does not occur."	**Text modified, and new Table 5.1 with a reference added to provide actual fast and slow fill results**

Comment	Response
5.2 Page 86, the following sentence needs to be fixed: "The CNG system suffers a weight penalty of 2,100 pounds with full tanks, and 2,358 pounds with empty tanks…" I'm not sure where 2358 comes from, and also I think the words empty and full are switched…	This line is actually correct. Natural gas is lighter than diesel at equivalent energy content, so the weight penalty of CNG tanks is larger when tanks are empty. **Added line to explain in Section 5**
6.3 Overall, the conclusions section is good. Just a few minor comments:	**No change required**
6.3 On page 98, one conclusion is "Achieving this level of benefit requires the use of complex and expensive technologies that are not yet fully developed, such as a waste heat recovery system." In this report, nothing was mentioned about the cost of the technology, I assume that information is in report #2.	**A reference to the cost report was added**
6.3 The conclusions seem to only cover Sections 2 and 3; sections 4 and 5 are not really mentioned at all in the conclusions section. It would be good to at least have a few key conclusions about the natural gas vehicles.	**New text added for Sections 4 and 5**
7.1 Overall, the appendices cover a lot of details in terms of the vehicle technology combinations and their results. There is sufficient technical detail in these sections.	**No change required**
7.1 It is clear that the appendix on the hybrid systems was written by different authors, the flow of that section is different, but adequate.	**No change required**
7.1 Some of the tables and figures in the appendix are inconsistent in style and formatting, but the information content is adequate.	**No change required**
8.1 Overall, the report is well organized and pretty clear. Just a few comments:	**No change required**
8.1 As mentioned earlier, the executive summary makes a lot of assumptions in terms of what is already known, therefore it may have limited use as a stand-alone document.	**Executive Summary rewritten**
8.1 Some of the different sections in the report end abruptly, without any concluding sentences which sometimes leaves the reader hanging.	**New lines added to Sections 3 and 5. New sections 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18 added**

Comment	Response
8.1 In the discussions about all of the different technology combinations it gets confusing in terms of what the baselines are. All the information is there, however it is necessary to read some sections a few times before it sinks in.	**Dozens of minor text changes made to clarify baseline references**
8.2 There is sufficient detail in the report, both in the main body and in the appendices. But sometimes you need to track multiple things between sections (and tables) of the report, and the appendices to fully understand the details. This is mainly due to the complexity of the analysis.	**No change required**
8.2 As mentioned previously, it is not clear to the reader how the different combinations of technologies were chosen, it seems somewhat ad-hoc in some cases. The reader is left wondering if other technologies could also be woven in, such as different types of hybridization.	**These issues are addressed in previous comments above.**
8.3 The strongest part of the report was section 2, in terms of the analysis and comparison of the different technology combinations. Sections 4 and 5 were both written very well and covered the key areas of costs and tradeoffs.	**No change required**
8.3 The weakest part of the report probably was the executive summary which probably doesn't do too well as a stand-alone document, it is really just a summary that you can understand once you have read the entire report.	**Executive Summary rewritten**

Comment	Response
8.4 Overall the information provided in the report is sufficiently detailed; various comments on specifics have been provided above. • As mentioned as part of the evaluations of Report #1, 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 maybe in the introduction. 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.	These comments were addressed by revisions to Report #1 as appropriate. Eco-driving aids and real-time navigation are out of scope. Reviews of infrastructure changes and operational techniques are out of scope. **No changes required**
9.1 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.	**No changes required**

Final Report #2

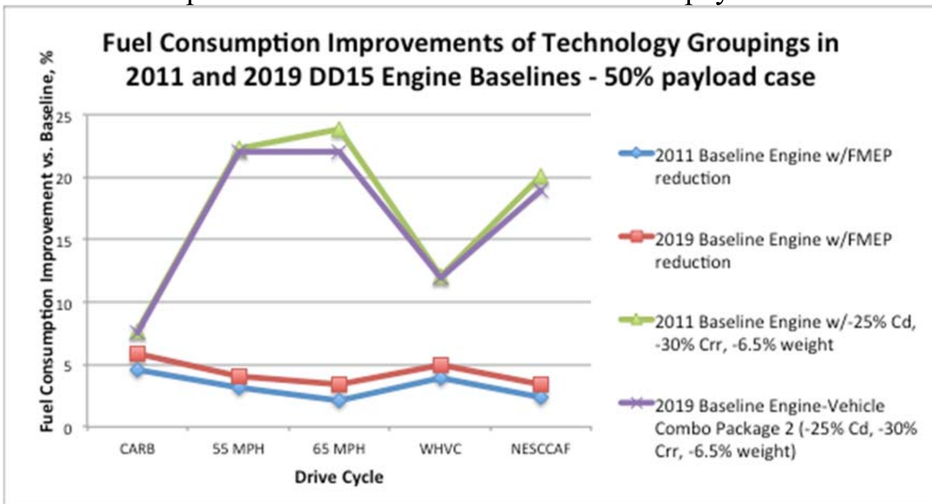
Susan Nelson Reviewer Comments and Responses

Comment	Response
1.1 A brief paragraph indicating the *principal* objective and authoring organization of each of the three individual reports. For example, the primary topic of the first report is to analyze the potential of medium- and heavy-duty truck engine and vehicle technologies to deliver reductions in fuel consumption during the 2014-2018 Phase 1 timeframe, introducing each technology one-by-one into a baseline engine and vehicle configuration. The second report evaluates costs associated with implementing fuel savings upgrades, including a few associated technologies – such as automatic tire inflation systems - that were not considered in the earlier engine and vehicle performance simulations. Finally, the third report establishes new engine and vehicle baselines for the post-2018 timeframe, and evaluates the potential additional reductions in fuel consumption that could be obtained by grouping together compatible technologies.	**New 3rd paragraph on introduction added**
1.1 A single table which presents the vehicles selected for analysis, the vehicle applications, the weight class and GVWR represented by each vehicle, the engine type(s) which were studied for each vehicle, and the drive cycles used in simulations of each vehicle to obtain fuel consumption predictions.	**Tables 1.1 and 1.2, and a reference were added to the introduction**

Comment	Response
1.2 The Introduction provides a clear and concise overview of the contents of the report. Other comments on Section 1 are listed below. • It should be highlighted that Section 2 technologies include a study of hybrid solutions for the pickup truck. Hybrid solutions were not simulated in Report #1. • The discussion of bottoming cycle and recuperator solutions should be moved to the paragraph describing Section 2, instead of being included in the description of Section 3. • In addition to predicting the degree of fuel savings that can be obtained through specific combinations of key technologies, Section 1.0 describes an ambition to identify technology combinations that are directly (linearly) additive, those which are additive but which demonstrate non-linear interactions that may not be predictable from simulations of individual technologies, and those which are in opposition. An analysis of technology interactions has not been explicitly presented in the report. Some clarification of how this objective will be accomplished, either by including a report section, or suggesting future research directions, should be provided.	**New line added to paragraph describing Section 2** **Discussion of bottoming cycle and recuperators moved to paragraph describing section 2** **New Sections added: 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18**

Comment	Response
2.1 The methodology used by the authors, while not necessarily employing the identical modeling tools, is consistent with the work of other excellent published research (Ricardo, 2011; Muster, 2000) in terms of both model selection and application for the analysis of engine and vehicle technologies. The process used in the current report follows the sequence: 1) development of engine simulation model for known production engine; 2) prediction of effects of technology upgrades expected by a future date to establish new engine models to serve as more appropriate baselines; and, 3) insertion of the new engine baseline model(s) into vehicle simulations to predict total fuel consumption across a range of drive cycles. A key feature of this methodology, also commonly used, is that engine function is not adapted for anticipated decreases in levels of road loads. Additional comments are given in Question 2-2, regarding engine downsizing. Use of a constant to express the tire coefficient of rolling resistance, Crr, is currently a widely accepted practice in vehicle simulations, even though the coefficient has weak dependence on vehicle speed and load in normal operating ranges (Laclair and Truemner, 2005). To be clear, the contribution of tire rolling resistance to *road load* (considered for practical purposes as a retarding force on the vehicle) is a linear function of total vehicle weight including payload under the constant Crr assumption. At some future point it may be of interest to incorporate tire rolling resistance road load as a function of vehicle load, vehicle speed, and tire pressure in simulation studies. The authors have been thorough in their explanations of engine technologies, providing details of how each technology works, and the techniques for incorporating each technology into the simulations. Speaking as someone who has limited experience in engines and engine technology, I can only add that the simulation treatments are credible, and the level of elaboration of the technologies contributes significantly to the understanding of the results.	**No changes required**
2.1 Two areas in which the report could be improved for clarity are the definition of engine/vehicle baselines and the treatment of technology interactions. Each area is discussed briefly for the example case of the DD15 diesel engine and T-700 vehicle.	**New sections added to discuss technology interactions. New text added in several sections**

Comment	Response
2.1 **Engine and Vehicle Baselines.** References to the DD15 engine models contained in Report #1 and Report #3 include years 2011, 2012, 2013, 2014, 2017 and 2019. It is understood that the 2011 engine refers to the GT-POWER model developed from test cell data on a 2011 production year DD15, and that this serves as the baseline engine used in Report #1 for technology comparisons. The sequence of engine model updates from that point should be described in a single paragraph, including the technologies or strategies that were applied at each update to arrive at the 2019 baseline engine. It is unclear whether 2011 and 2012 refer to the same engine model, and similarly for versions 2013 and 2014, and whether any model other than that from the 2011 production year and the 2019 DD15 projected baseline was used in any simulations.	**New text added to the first paragraph of Section 2.3.2**
2.1 On the vehicle side, it should be clarified there are no differences made to the T-700 vehicle model during the course of the simulations other than replacement of the 2011 engine model with the 2019 baseline engine, e.g. no weight, aero, or tire improvements are assumed for the T-700 in going from the analysis of Report #1 to Report #3.	**New text added to the first paragraph of Section 2.3.3**
2.1 **Interactions of Combined Technologies.** Analysis of technology interactions has not been specifically presented in the report. For example, is fuel consumption due to a reduction in Crr affected by different levels of the coefficient of aerodynamic drag, Cd, on a given vehicle? Typically, we would say the answer is no, given the definitions of Crr and Cd embedded in the modeling. One way to explore additive effects on a very macro level would be to compare whether a technology, or package of technologies, provides the same level of fuel consumption improvement when applied to two different baselines. The following graph shows the percent improvement in fuel consumption due to the same engine friction reduction (FMEP) for both the 2011 and 2019 baseline engines, across all drive cycles. The 2011 baseline DD15 + FMEP improvement (case #11 in Report #1) is compared to the 2011 baseline; likewise, the 2019 baseline DD15 + FMEP improvement (DD15 package #1 in Report #3) is compared to the 2019 baseline engine model. Similarly, the combined effects of a 25% reduction in Cd, 30% reduction in tire rolling resistance, and 6.5% reduction in empty vehicle weight can be compared by adding the individual contributions to establish an improvement in fuel consumption versus the 2011 baseline (addition of cases II, JJ, and KK-6.5% from Report #1) compared to the T-700 Combined Engine-Vehicle package #2 in Report #3 which combines the same technologies with the 2019 baseline engine model.	**New sections added: 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18**

Comment	Response
These comparisons are shown below for the 50% payload case.  	
2.1 From these results [see figure above], we would be likely to conclude that these technologies are largely additive, with small differences due to simulation uncertainties, modeling assumptions, or perhaps, real differences in interactions. The friction reduction cases show a consistently greater improvement when applied to the 2019 baseline versus the 2011 baseline engine. Vehicle weight, rolling resistance, and aerodynamic drag are expected to be additive if the baselines are similar enough, as the 2011 and 2019 DD15 models appear to be. More interesting cases could consider combined engine modifications and vehicle technologies, such as substituting the 2019 DD15 engine package 2 (downspeeding + partial FMEP reductions) into the T-700 combo package #2 (25% reduction in Cd, 30% reduction in tire rolling resistance, and 6.5% reduction in empty vehicle weight) to compare with an analogous 2011 package, which may show some evidence of interactions	The analysis suggested here would be very interesting, and would probably be best achieved using a design of experiments evaluation. Out of the project scope, so **no change**
2.2 **General Comments.** The current studies have benefitted greatly from well over a decade of continuous and concentrated research into medium- and heavy-duty truck fuel savings technologies summarized by the National Research Council (NRC, 2010 and 2014), the annual merit reviews of the four SuperTruck projects which are reaching the demonstrator phase (Jadin, 2012; Gibble and Amar, 2013; Koeberlein, 2014; Singh, 2014; Rotz and Ziegler, 2014; Delgado and Lutsey, 2014), the 21st Century Truck Partnership (2006), and other research such as an earlier study by MIT (Muster, 2000). Taken together, these programs have provided a generally consistent, progressive and widely reviewed foundation for the selection of fuel savings technologies.	**No change required**

Comment	Response
2.2 In addition, the level of stakeholder involvement throughout the process is striking, encompassing OEMs and commercial truck equipment suppliers, research labs and universities, regulatory bodies, trucking industry representatives, fleet and maintenance managers, and drivers. Technologies have frequently received significant coverage in end-user literature (Berg, 2014; Brawner, 2015; Lockwood, 2015) and at industry meetings (TMC, 2015), promoting broad dialog in the industry about the advantages/disadvantages, costs, and implementation strategies of new trucking equipment. Given this context, technology combinations for the T-700 are coherent with approaches reported by other researchers and by the SuperTruck projects, and represent combinations that are pertinent to fuel consumption evaluations.	**No change required**
2.2 **Technology Selection and Pairings - 6x2 Axle Configuration and Tires.** In one study of 6x2 versus 6x4 axle configurations (NACFE, 2014), a 6x2 "package" was identified as containing the following components: wide-base single drive tires on the drive axle, wide-base single trailer tires on the tag axle, "tall" axle ratio of around 2.6:1, use of low viscosity axle lubricant, and direct-drive transmission with down-speeding applied in some cases (approaching T-700 Combo Package 3, excluding aero and accessory power reduction). The NACFE study attributed fuel economy improvements in the range of 1.6% - 4.6% to the use of 6x2 axles, with various adjustments made to account for differences in the make-up of the tested vehicle packages. A 6x2 axle can permit an overall reduction in tire rolling resistance on the vehicle if trailer tires are used on the tag axle instead of drive tires. An example shown in the following table using SmartWay thresholds for steer, drive and trailer tires indicates a 5% reduction in effective vehicle rolling resistance coefficient by substituting trailer tires on the tag axle, e.g. from a value of Crr(veh) of 5.95 kg/T to 5.63 kg/T. The effective vehicle Crr(veh) is given as: $Crr(veh) = [\ \Sigma_j\ Crrj * Zj] / [\ \Sigma_j\ Zj\ ]$ where, Crrj is the coefficient of rolling resistance for tires on axle j, and Zj is the total load on that axle. The rolling resistance decrease is considered as an enabled tire contribution to vehicle fuel consumption improvements.	**New paragraph added in Section 2.3.3.3**

Comment	Response
(see table and text below)	New paragraph added in Section 2.3.3.3

Description	Steer Axle Weight, lb	6x4 Drive Tandem or 6x2 Drive Axle Weight, lb	6x2 Tag Axle Weight, lb	Trailer Tandem Weight, lb
100% Payload case, Total vehicle weight 80000 lb., 6x4				
Load distribution of 46040-lb payload tractor-trailer	12000	34000	n/a	34000
% weight carried by axle or tandem	15%	43%	n/a	43%
Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)	6.5	6.6	n/a	5.1
Rolling resistance contribution of axle to Crr(veh), kg/T	0.98	2.81	n/a	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%	n/a	36%
100% Payload case, Total vehicle weight 80000 lb., 6x2				
Load distribution of 46040-lb payload tractor-trailer	12000	17000	17000	34000
% weight carried by axle or tandem	15%	21%	21%	43%
Jan 2015 SmartWay thresholds for Crr tires, kg/T (ISO 25850)	6.5	6.6	5.1	5.1
Rolling resistance contribution of axle to Crr(veh), kg/T	0.98	1.40	1.08	2.17
Total effective vehicle rolling resistance coefficient, Crr(veh), kg/T	5.63			
% Contribution of axle, tandem to total effective vehicle Crr(veh)	17%	25%	19%	39%

The NACFE study included some preliminary data indicating that the 6x2 configuration can decrease the wear life of the tires on the drive axle by approximately 1/3, potentially requiring more frequent replacement of tires on this axle. It should be noted that under normal operations trailer tires (on a trailer axle) are likely to have half the wear life of drive tires on a 6x4 configuration (Michelin, 2011). This suggests that trailer tires on the 6x2 tag axle would also need to be replaced more often than drive tires on a 6x4 axle configuration. Effectively, this suggests that tires on both drive and tag 6x2 axles would need to be changed out more often than tires on the drive tandem of a standard 6x4 truck.

This aspect of 6x2 configurations will need to be considered when calculating tire life cycle costs. It should be further noted that heavy-duty truck tires have a non-zero residual value due to the casing which can be retreaded several times. This tire residual value was not reported in the cost analysis of Report #2 (Tetra Tech draft cost study).

Certain new 6x2 products are being developed with the capability to shift load from the tag axle to the drive axle to improve traction. Under this operation, assurance of sufficient tire inflation pressure to support the increased load is critical, as loading can exceed the standard level of 17,000-lb per axle. Wheels must also be able to support the maximum loading.

Comment	Response
2.2 **Aerodynamic Fitments and Tires.** Report #3 does not stipulate specific aerodynamic treatments or equipment, but it would not be unusual for a future truck to deploy side skirting which covers both the drive and trailer tandem axles, potentially cutting off convective tire cooling. Airflow around the wheel ends will need to be managed to ensure that tires, wheels, and braking systems are all adequately cooled if isolated from normal ambient airflows.	**New line added in Section 3.3.3.2. Also added mention of the need for inspection access.**
2.2 **Engine Downsizing and Reduced Road Load**. Engine downsizing is a technology that was not carried over into the combined technologies study. However, combinations of road load reductions can enable engine downspeeding and downsizing in commercial vehicles. This approach has been described in both Daimler and Volvo SuperTruck projects (Delgado and Lutsey, 2014) and has been used in the most recently displayed Daimler SuperTruck demonstrator (McNabb, 2015). An estimated reduction in road load power demand may shift the engine operation to a zone of lower efficiency on the fuel map, which is then compensated for by engine downspeeding and downsizing.	**New 2nd paragraph of Section 2.3.2 added**
2.3 Classes 2b, 6, and 8 commercial vehicles have historically represented the combination of the greatest number of commercial vehicle classes on the road and those which consume the most fuel. Ninety percent of the fuel consumed by all medium- and heavy-duty trucks can be attributed to these classes (NRC, 2014). This characteristic, together with the vehicle selection process described in Report #1, support the decisions to include the Ram pickup, T-270 straight truck, and T-700 Class 8 tractor in the study. Given that data was available to support analysis of the Ford F-650, and that the vocational sector has perhaps been under-represented in fuel consumption studies to date, makes this vehicle a useful addition to the project.	**No changes required**
2.3 Across all vehicles, including light-duty, tire rolling resistance is estimated to account for 8%-18% of the total fuel energy consumption (engine losses being 50% or greater). The amount of fuel savings due to reductions in rolling resistance can vary as much from vehicle to vehicle as from drive cycle to drive cycle. Estimated sensitivities are reported to range from 10:0.5 to 10:1 in light duty vehicles to 10:1 to 10:3 for medium- to heavy-duty vehicles (Hall and Moreland, 2001). A ratio of 10:3 would be interpreted as a 10% reduction in tire rolling resistance coefficient generating a 3% reduction in fuel consumed, which is a return ratio that approximates Class 8 tractor-trailer sensitivity.	**No changes required**

Comment	Response
2.3 Because of differences in fuel consumed due to rolling resistance for different drive cycles, it is important that each vehicle in the study be subjected to multiple cycles, covering a wide range of operations for a vehicle type. It is unlikely that a single drive cycle can coherently represent vehicle usage. The drive cycles used in the study are familiar and widely used, and, taken as a package for each vehicle type, cover many truck applications. The key decision will be how to combine all or some of the drive cycles to represent the overall usage of each type of vehicle. One approach is to use weighted combinations of fuel consumption from some or all of the cycles studied for a given vehicle category, the values of the various weighting factors being the crucial choice. Alternatively, individual performance targets could be set for each vehicle class for one or more individual drive cycle(s).	**No changes required**
2.4 The computer models chosen for engine/vehicle simulations, and the overall modeling approach, are similar to those typically used by other researchers (Laclair and Truemner, 2005; Gibble and Amar, 2013; Ricardo, 2011; Muster, 2000). One notable difference between researchers is whether a driver model is incorporated in drive cycle simulations; an evaluation of this difference is outside my area of expertise.	**No changes required**
2.5 Typical simulation studies assume the tire rolling resistance coefficient, Crr, to be constant across different levels of payload and different speeds, given that the dependence of Crr on load and speed is relatively weak in the normal range of truck operating conditions. Use of a constant coefficient greatly simplifies calculations and sensitivity studies while generally providing satisfactory results.	**No changes required**

Comment	Response
2.5 Tire rolling resistance is a function of load, inflation pressure, speed, applied torque and steer angle, as well as tire temperature, camber, and the wheel used. Moreover, the tire operating temperature, a highly influential parameter for tire pressure, depends on the history of the conditions under which the tire has operated (Laclair, 2005). One approach to determine transient tire rolling losses is to use data from a coastdown machine test to solve for the coefficients in the following equation (Laclair, 2005; Hall and Moreland, 2001): $Fr = (P^{\alpha})(Z^{\beta})\ (a + bV + cV^{2})$ In which: Fr = tire rolling loss P = tire internal pressure Z = vehicle weight carried on the tire V = speed a, b, c, α, β are fitted coefficients. To date the current test method, SAE J2452, has been specified for passenger car and light-truck tires only. In actual field usage, the tire warms and cools according to operating conditions, altering the internal pressure which in turn dictates actual rolling resistance at any given moment. Predicting tire rolling resistance during the course of a transient drive cycle can be a challenge. On a Class 8 tractor-trailer using steer, drive, and trailer tires, the operating conditions for each tire type are different for each axle. In terms of fuel consumption, a more complex tire rolling resistance model may not offer any improvements in prediction over models based on constant Crr. I am not aware of any studies comparing the use of constant Crr to represent rolling resistance versus the above equation in order to calculate fuel consumption for commercial trucks.	Interesting information, but taking the slight non-linearity of tire rolling resistance into account was beyond the project scope. **No changes required**
2.6 **Technology Interactions.** Although occasional comments on the potential additive nature of certain technology groupings are made in the report, this topic has not yet received in-depth treatment. Identification of interactions is one of the primary objectives of the study, and would make a good concluding section for the chapter.	**New sections added: 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18.** However, full in-depth treatment of interactions is out of scope.

Comment	Response
2.6 **Out-of-Scope Technologies.** A brief listing of out-of-scope technologies, such as start-stop, driver habits, active tire pressure controls, continuously variable transmissions, and route optimization can be beneficial for the reader, and also set the stage for future research.	**New second paragraph of Section 2.3.3 added**
2.6 **References.** The following report discusses differences and similarities between light-duty and heavier pickups and vans, including fuel savings technologies, market and use patterns, and current GHG and fuel consumption standards. Lutsey, N., "Regulatory Considerations for Advancing Commercial Pickup and Van Efficiency Technology in the United States", The International Council on Clean Transportation, April 2015, http://www.theicct.org/sites/default/files/publications/ICCT_pickup-van-efficiency_20150417.pdf.	No new post-2012 references. **No change required**
3.1 Across the discussions of vehicles, engines, and drive cycles in this section, frequent reference is made to the relative importance of one component of road load versus another on a case-by-case basis. Given that there are generalizations that can be made concerning aerodynamic drag, tire rolling resistance, and vehicle lightweighting, it is recommended that an additional report section be included which presents the classical equations for each of these components. The material could be included at the beginning of Section 3.0 or in an appendix, and would make evident the relationships of: • Aerodynamic drag force as a function of velocity squared, coefficient of aerodynamic drag, and vehicle cross-sectional area exposed to wind; • Vehicle inertial forces as a function of vehicle mass and acceleration; • Tire rolling resistance forces as a function of vehicle mass and the tire coefficient of rolling resistance. This would make more intuitive the effects of vehicle weight reductions (affecting the road load contributions of both vehicle inertia and tire rolling resistance), drive cycle average speed and speed variability (impacts of aerodynamic drag and inertial effects), and additive improvements due to Cd and Crr (linear relation between the coefficients and road load, and, on the face of it, no interactions between the two coefficients since they do not share any underlying factors in their equations). Fuel consumption sensitivities could be	Creation of a textbook-like section presenting all the equations is out of scope. **No change**

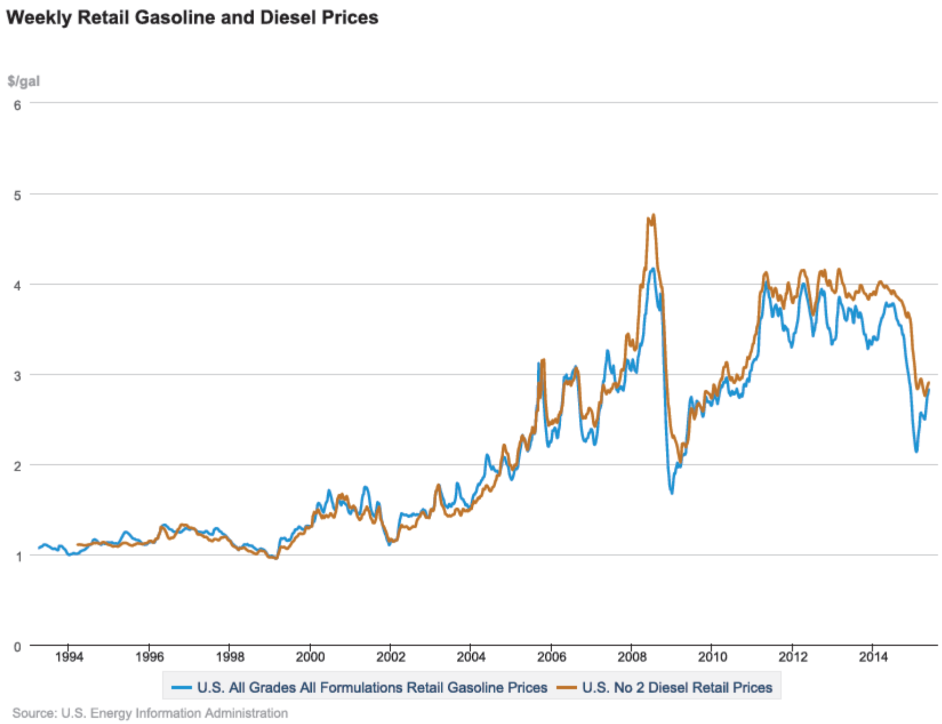
Comment	Response
more readily inferred, even for vehicles not subjected to simulation studies, knowing that, for example: • Fuel consumption of vehicles with greater projected frontal area has greater sensitivity to changes in Cd; • Fuel consumption of heavier vehicles is more sensitive to changes in Crr; • Steady-state drive cycles have low sensitivity to lightweighting. An example of a diagram that can be useful for explaining the relative magnitudes of the road load components during the course of a drive cycle can be found in Figures 29 and 30 of Muster, 2000, illustrated for a highway driving cycle. Similar graphs could be developed for selected cases in Report #3. This visual aide may illustrate more readily and broadly the conclusions of Section 3.1.	These points are made at appropriate locations in the text. **New Section 3.4 added** No new figures, **but new Section 3.4 added**
3.2 **Tire Rolling Resistance Coefficient**. Whether the projected reductions in tire rolling resistance coefficient are appropriate depends on what is considered as the baseline Crr value for each vehicle, and whether that value represents a sales-weighted average tire or a best-in-class tire. However, the linear relationship between percent change in Crr versus percent change in fuel consumption can be used to evaluate the impact of potential tire improvements, even if machine measured Crr values are not exactly represented. For pickup trucks, Crr reductions summarized in Lutsey (2015) suggest that 10%-20% reduction is a reasonable working range.	**No change required**
3.2 Class 8 tractor-trailers may present more opportunities for rolling resistance reductions than the other study vehicles since the Class 8 vehicle is equipped with several different tire types – steer, drive, and trailer – with each tire type optimized to the operating conditions of its specific axle position. Class 8 enabling technologies, such as the use of 6x2 axle configurations, can permit the vehicle to be fitted with an overall lower Crr tire set. The Ram pickup, F-650, and T-270 use the same tire fitments in all wheel positions, so improvement options are more likely to be limited to direct reductions in Crr.	**No change required**
3.2 **Aerodynamic Drag/Weight Reductions.** Lutsey also reports opportunities for improvements of 10-20% in Cd and also in vehicle weight reductions, based on light-duty simulations. Industry publications indicate Cd ranges of approximately 0.4 – 0.42 for the 2009 model year of this class of pickup truck (Witzenberg, 2009), and Cd ranges of 0.36 – 0.41 for 2015 model years (Sanchez, 2014). The latest Ford F-150 EcoBoost includes a 700-lb weight reduction, or approximately 12-14% of the empty vehicle weight. These values, although not in the same vehicle class, support the range of Cd and weight reduction percentages considered in Report #3.	**No change required**

Comment	Response
3.3 This combination of vehicles and engines represents an opportunity to compare potential interactions between engine types and each of the three primary road load components. As the weights of the F-650 and T-270 are relatively close in this exercise, it is not surprising that the two vehicles show very similar sensitivities for Crr and lightweighting sweeps.	**No change required**
3.3 For the cases presented, there are small differences in engine sensitivity to lightweighting. It would have been interesting to see if more significant differences in sensitivity across the three engine types are observed when paired with Crr reductions.	This would require many new simulation runs. Out of scope, so **no changes**
3.4 The rolling resistance results for all three vehicles – Ram pickup, F-650, and T-270 - are within the ranges of vehicle sensitivities as a function of weight class discussed in the response to Question 2-3.	**No change required**
4.1 Section 4 outlines primary characteristics of vocational vehicle operations that may limit the ability to reduce fuel consumption using lower aerodynamic drag or tire rolling resistance, as well as lightweighting to some degree. This does not mean that these technologies should not be pursued; even moderate improvements can deliver consequential fuel savings. Opportunities for vocational vehicle fuel savings for gasoline and diesel versions have most recently been outlined by Lutsey (2015, Table 3). The majority of these technologies have been addressed in the current report, but there may be others that warrant future consideration.	**No change required**
4.1 Vehicle sensitivities can be better compared in graphical summaries similar to Figures 3.7 and 3.8 of the T-700 analysis in Report #1. These graphs report percent fuel savings versus progressive improvements in Cd and Crr, and could be developed for vehicle weight reductions. Including several charts of this type in Report #3, also adding T-700 results from the first report, will show differences in vehicle sensitivities more clearly.	Figures 3.1 – 3.9 show vehicle sensitivity to Cd, Crr, and empty weight. The format does not match Report #1, but the data is there. **No change**
4.1 A review of T-270 vehicles offered for sale on the website referenced below confirms that a wide range of axle ratios are actively used in the industry. A quick scan showed used vehicles available with axle ratios of 3.9 – 6.17, with 5.29 being the most common. This reinforces the idea of diversity of usages for vehicles in this category, including considerations for vehicle performance needs of grade capability, acceleration, max speed, and startability as well as fuel consumption, as the authors have briefly described. http://www.truckpaper.com/list/list.aspx?bcatid=27&Manu=KENWORTH&Mdltxt=T270	This info matches the range of axle ratios evaluated in the report, and also the choice of 5.29 as the baseline ratio. **No changes required.**

Comment	Response
4.2 The calculations in Section 4.1 of the report cover the range of probable conditions under which a gasoline engine could compete with a diesel version in the T-270. Payback calculations are based on initial purchase price and the fuel consumed, which are the largest vehicle cost items. Other elements that are typically included in payback calculations, described a recent ATRI summary (Torrey and Murray, 2014) are listed below: • Repair and maintenance; • Insurance premiums; • Permits and licenses; • Tires; • Tolls; • Driver wages and benefits. All costs associated with the items on this list are likely to remain equivalent for both engine fuel types, with a possible exception in the Repair and Maintenance category, which is not accounted for in the Section 4.1 analysis. The ATRI results indicate that across the survey respondents, which include a range of truck classes and is skewed towards long haul, fuel accounted for $0.645/mile of operational cost in 2013, compared to Repair and Maintenance costs of $0.148/mile. An additional factor for payback calculations is residual value, also not considered here. Data reported for the relatively small sample of straight trucks in the ATRI report indicated 32,901 average annual miles per truck, with an average trade cycle of 9 years. Assuming no differences in maintenance costs, the analysis in Report #3 depends on: • Difference in vehicle purchase price (V-6 and V-8 both $9000 less expensive than the diesel); • Differences in fuel consumption between engines; • Cost of gasoline (taken here as the base); • Price difference between the cost of gasoline and diesel fuel. To which we might add, • Annual mileage; • Mix and weighting of drive cycle simulations. Given the variety of applications for this vehicle class, it is difficult to make a case for other than equal weighting of the 6 drive cycles simulated in the study. An increase in assumed annual mileage will make a more favorable case for diesel engines; an annual mileage decrease will favor gasoline engine versions. Including annual mileage as a variable rather than as a constant in the calculations could also be of interest, but it is probably unlikely to significantly change the conclusions of the existing analysis based on 25000 miles annually.	This analysis confirms the analysis of Section 4. **No changes required** This analysis confirms the analysis of Section 4. **No changes required**

Comment	Response

Certainly, the levels and volatility of fuel prices are key to the payback time required to overcome the purchase price differential between gasoline and diesel vehicles. Another version of Figure 4.1 shown in Report #3 comes from the U.S. Department of Energy, Energy Information Administration website (eia.gov), and shows the history of both gasoline and diesel prices in the U.S. (from which Figure 4.1 in Report #3 can be derived). During the period from about 2011 to the end of 2014, volatility of gasoline price has largely driven the differences between the costs of the two fuels, although both fuels experienced significant price drops in the first half of 2015.



Tax differences between the two fuels cannot account for volatility, however, a certain structural price difference is built into current $/gallon values, as shown in the table below, also taken from the eia.gov website. This impact can change based on public policy regarding fuels, governing authority needs for revenue streams, as well as other factors not strictly market related.

Tax entity	Tax on Gasoline, $/gal	Tax on Diesel, $/gal
Federal	0.18	0.24
State – minimum (Alaska)	0.08	0.08
State – maximum (Pennsylvania)	0.516	0.653
Range per gallon of fuel	0.26 – 0.70	0.32 – 0.90

Comment		Response
	In the end, the future of fuel pricing is difficult to predict, especially in the current period, but we might say that the most likely scenarios would be in the range of \$0-\$0.25/gal price penalty for diesel. Payback time is extremely sensitive in this range, as seen in Table 4.2 of the report. Given a 9-year average trade cycle and gasoline prices in the range of \$3-\$4/gal, there are a number of scenarios for which diesel and gasoline engine solutions could be roughly at parity.	This analysis confirms the analysis of Section 4. **No changes required**
5.1	The information presented in Section 5 aligns with other published analysis of the factors and costs associated with the use of natural gas systems in commercial vehicles. Listings of engine offerings in Report #3 are consistent with earlier summaries presented in Table 7.1 of an ACT whitepaper (ACT, 2012), and cover updates in product offerings since that time. The most commonly mentioned considerations related to the adoption of natural gas vehicles are covered in Section 5.0: • Vehicle acquisition costs – driven by both engine and on-board fuel storage differences; • Natural gas versus diesel fuel price differentials; • Fueling station availability and infrastructure; • Government incentives; • Downtime concerns due to natural gas re-fueling times; • General discussion of maintenance; • Efficiency differences between diesel and natural gas solutions, including engine efficiencies, weight and aerodynamic effects; • Impact of wheelbase is a consideration discussed briefly in Section 5.0 that is not often covered elsewhere.	**No changes required**
5.1	An overview of payback and operational considerations for natural gas vehicles from a fleet perspective is reported by J.B. Hunt (Mounce, 2014). This whitepaper covers purchase price upcharge for natural gas options, observed differences in fuel consumption, vehicle weight comparisons, fuel cost comparisons, as well as presenting two hypothetical scenarios for return on investment calculations, looking at natural gas versus diesel over a 5-year analysis period. Additional maintenance costs were estimated at \$0.02-\$0.04 per mile for spark-ignited NG engines. Questions of resale, or residual values, of natural gas vehicles are at present unknown. It should be noted that this fleet continues to study the performance and opportunities of natural gas options.	**New text, very similar to the reviewer's, and new reference added to Section 5.7.5.**

Comment	Response
5.1 Several elements that can support future ROI analysis, but which are not included in Report #3, are listed below: • Costs to upgrade existing maintenance facilities plus routine operational maintenance costs for natural gas applications; • DEF costs for diesel, estimated at around 2-2.5% of fuel costs; • Comparison of natural gas versus diesel options in terms of risks and potential to meet emissions requirements across the range of GHG and criteria pollutants. A recent article discusses latest estimates of potential methane emissions associated with fleet conversion from diesel to natural gas fuels (Camuzeaux et al., 2015).	**No changes required**
5.2 Explanations of the current state of natural gas options and considerations are suitable and properly described. Other details are discussed in the response to Question 5-1.	**No changes required**
6.1 Section 6 is well written, concise, and clear. Descriptions of potential fuel savings, function and impacts of key technologies and packages, and relevant drive-cycle results are comprehensive without getting lost in details. These are by far the most important conclusions of the study project.	Note that the original Section 6 now forms the bulk of the Executive Summary. **No changes required**
6.1 That being said, conclusions from the sections on hybrid solutions, payback calculations for gasoline versus diesel engines in vocational vehicles, and the analysis of natural gas fuel solutions are missing. It is not evident where these items could be inserted into Section 6 without diminishing the impact of the findings contained in this chapter in its current form.	**New paragraph on hybrids added in Section 6.3. New sections 6.4 on gasoline and 6.5 on natural gas have been added.**
6.2 Table 6.3 presents the key conclusions in a compact format. However, the approach used to derive the fuel savings percentages in Table 6.3 from the results tables in Section 2 should be explained.	**Explanation added in 1st paragraph of Section 6.6 (now ES)**
6.2 While not at the same level of importance as the results of Table 6.3, conclusions on additive versus non-additive technologies, enabling technologies, and opposing technologies should be addressed if possible.	**Several new subsections have been added to Section 2**

Comment	Response
6.3 Interpretation of Tables 6.1 and 6.2 can be confusing. A positive percentage means greater fuel consumption (accounting for differences in energy content between the fuel types and the thermal efficiency of the respective engines) of the V-6 or V-8 gasoline engines compared to a projected 2019 diesel baseline. A negative percentage means the gasoline engine consumes less fuel than the diesel, again considering both fuel energy content and engine thermal efficiency. One way to clarify the reading of the tables is to provide a short explanation that walks through one column in each table.	**A new paragraph is added just below Table 6.1. Also, Tables 6.1 and 6.2 are expanded to include results from the baseline V-8, to help illustrate the benefits of improved gasoline engine technology.**
7.1 Vehicles and vehicle technology input data are properly and adequately described in Appendix C for the purposes of the simulations. For clarity concerning the rolling resistance coefficients, it is recommended that the updated discussion of the derivation of Crr values leading up to Table C.9 of Appendix C in Report #1 also be included in Appendix C of Report #3, just before Table C.18.	**Text from Appendix C of Report #1 added**
7.1 In Appendix B, Section 1.1 of Report #3, does "original" baseline refer to the 2011 production DD15 for which a test cell dataset was available, or does the term refer to the simulation result of "Technology #7 – Asymmetric Turbo" from Report #1, which was the exercise to model a 2013 DD15? This point should be clarified for both the text and figure titles in this section.	**Clarification added to text.** We are referring to the 2013/14 non-turbocompound baseline.
7.1 To reinforce the current study a stand-alone report, it may be beneficial to include the graphs of the drive cycles again in Report #3.	**Text and Figures describing drive cycles copied from Report #1**
7.1 Aerodynamic drag coefficients Cd w/Trailer of the Dodge Ram and baseline and reduced CdA of the T-700 do not match in comparing Table C.17 of Report #3 with Table C.8 of Report #1.	The values for the Ram with trailer in Table C.8 of Report #1 are wrong and have been corrected. The frontal area of the T700 was accidentally reduced by 3.5% between Reports 1 and 2. This does slightly affect Report 2 results. **Clarification added in Report 2, Appendix C**

Comment	Response
7.1 Baseline tire rolling resistance coefficient given in Table C.18 of Report #3 for the Dodge Ram does not match the value shown in Table C.9 of Report #1 (as a side note, the Reduced value of Crr reported for the Dodge Ram in Table C.9 of Report #1 should have been 0.005460, and not 0.05460, given the baseline Crr listed in that table).	**The value in Table C.18 was wrong, and has been corrected to 0.0078.** This error did not affect the project results.
7.1 Report #3 Sections 2.3.2.4, 2.3.2.5, 2.3.2.6, 2.3.2.7 and 2.3.2.9 refer to Appendix D for discussion of waste heat recovery systems. Section 5.3 also makes reference to Appendix D for information on natural gas vehicle prices. However, Appendix D in the draft of Report #3 is devoted to hybrid systems only.	**References to Appendix D corrected to read "Appendix B"**
8.1 The report is extremely detailed in the descriptions of selected vehicles and their characteristics, the fuel savings technologies, engine technologies in particular, as well as the simulation models used and engine simulation outputs. As in the first report, this can make for some difficult reading. However, since it is infrequent that a study of vehicles, engines, and technologies of this breadth is undertaken, it is felt that the level of detail will in fact be helpful over time, to document as thoroughly as possible the way each technology is understood to work, the assumptions and approximations made in simulations, and how results were interpreted.	**No changes required**
8.1 The ordering of the main report sections is logical. It is clear how the information in one section is supported by the analysis of the preceding section.	**No changes required**
8.1 Some comprehension difficulties may arise due to the changing order in which vehicles and engine technologies are presented from section to section. For example, in the Executive Summary a discussion of the DD15 engine and T-700 truck is followed by the discussion of medium-duty and pickup truck gasoline engines, whereas in Section 2 the medium-duty diesel engine discussion comes first. Vehicle technology packages are first described for the F-650 in Section 2, but the first parameter sweeps are presented for the Ram pickup in Section 3. A consistent sequencing of vehicles and engines throughout the report would be very helpful for the reader in keeping the progression of technology packages clear.	**Sections 3 and 6 reordered to match the ES, introduction, and Section 2**
8.1 As mentioned in the response to Question 2-1, the path taken from the initial 2011 baseline DD15 engine through the sequence of interim model upgrades leading up to the 2019 DD15 baseline should be summarized in one paragraph. Then consistent terminology should be used to refer to the specific baselines throughout the rest of the report.	**New text added, and descriptions of baselines changed throughout the report**

Comment	Response
8.1 The process of engine model development is given in Section 2.2, but it is difficult to get a sense of what information is used for model building and calibration, and what is used for model validation. Even though the reader is referred to Appendix A for details, a summary statement describing which charts are used for quality checks during the modeling process reinforces confidence in the approach.	After reviewing the text of Section 2 and Appendices A and B, we believe that they provide a solid description of the information used to build and calibrate the engine models. **No changes**
8.1 Other recommendations that could aid the reader's comprehension could include (some items mentioned earlier in this review): • List each DD15 and T-700 technology package in separate paragraphs in the Executive Summary. • A table of study vehicles, engines, and drives cycles included in the Introduction, as mentioned in the response to Question 1-1. • Move Section 2.3.9.17, referring to the F-650, to its proper location in the report, or update the section title. (This section currently sits in the middle of the Ram engine discussions.) • Bring T-700 sweeps results for Cd, Crr, and weight into Report #3, and present the sweeps results for all vehicles in the same format as shown in Figures 3.7 and 3.8 of Report #1.	**Paragraphs broken up** **Tables 1.1 and 1.2 and a reference to Table 2.10 added to the introduction** **Section moved** Addressed above. **No change**
8.2 The updated discussion of the derivation of Crr values leading up to Table C.9 of Appendix C in Report #1 should be repeated in Appendix C of Report #3, just before Table C.18.	**New text added in Section C2.3**
8.3 The most impactful parts of the report document the combined engine-vehicle technology package simulation results.	**No change required**
8.3 While not particularly weak, the sweeps section of the report could be strengthened by including the standard equations for the components of road load – aerodynamic drag, tire rolling resistance, and vehicle inertial effects due to accelerations (excluding grade for the moment) – then charting the proportion of power demand due to each road load component during the execution of a particular drive cycle. These proportions are frequently referred to in the explanations of the various vehicle sensitivities. The exercise could be accomplished for selected cycles for any vehicle, and would help illustrate the changing proportions of engine power required to overcome each component as the cycle proceeds.	Out of scope. **No change to the text**

Comment	Response
8.4 The focus of this report is fuel consumption. But as multiple technologies are combined there are greater opportunities for one technology to impinge on non-fuel related performances of another. In the case of tires, the primary functions are to: 1) support the weight of the vehicle and payload; 2) transfer forces between the vehicle and road surface for steering and vehicle control, acceleration, and braking; and 3) isolate payload and vehicle occupants from driving surface roughness or irregularities (Lindenmuth, 2005). Ancillary performances include tread wear life, tire rolling resistance, and durability, the latter being of particular significance for heavy duty truck tires in order to support retreading. Fuel savings systems that may combine to increase mechanical or thermal stresses on tires, or any other vehicle component for that matter, will require careful integration to ensure that the final vehicle solutions continue to deliver the expected suite of performances at the component level.	These considerations are beyond the project scope. **No change to the text**
9.1 I would recommend the report be published with (a) minor revisions to improve readability and for minor corrections, specifically addressing clarification of the DD15 baselines, the bullet points outlined in the response to Question 8-1, and the updates to the appendices described in the responses to Questions 7-1 and 8-2.	**Changes to the report described above**
9.1 The technology reports within the scope of this project provide thorough, comprehensive analysis of the opportunities for fuel savings in the commercial truck sector, and should serve as valuable references for both rulemaking and for future research.	**No change required**

Final Report #2
William de Ojeda Reviewer Comments and Responses

Comment	Response
1.1 The introduction is rather brief. It is recommended that Section 1 be expanded to: - Include a description of the "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles". This may be done via table (see below). The text could include applicability: combination tractors, vocational vehicles, HD pickups and vans. May also for completeness includ US EPA SmartWay requirments (tractor and trailer aerodynamics, low rolling resistance tires) and applicability (53' or longer trailers or box type). It may also include motivation (improved emissions and fuel savings via adoption of new technologies, harmonize standards). Finally, a timeline for adoption may be included.	This would make a good introduction section to the Phase 2 regulations themselves, but it is out of scope for this project. **No change to the text**

HD Combination Tractor Vehicle Standards (gCO2/ton-mile)						
	2014-2016 MY			2017 MY and beyond		
	Class 7	Class 8		Class 7	Class 8	
		Day Cab	Sleeper Berth		Day Cab	Sleeper Berth
Low Roof	107	81	68	104	80	66
Mid Roof	119	88	76	115	86	73
High Roof	124	92	75	120	89	72

Vocational Vehicle CO2 Standard (gCO2/ton-mile)			
	LHD Class 2b-5	MHD Class 6-7	HHD Class 8
2014 MY	388	234	226
2017 MY	373	225	222

Final HD Diesel Engine Standards (gCO2/bhp-hr)					
	LHD (2b-5)	MHD (Class 6-7)		HHD (Class 8)	
		Vocational Veh	Tractors	Vocational Veh	Tractors
2014-2016 MY	600	600	502	567	475
2017 and Later	576	576	487	555	460

Comment	Response
- Include a summary of the engines and vehicles per Table 3.1 VEHICLE AND ENGINE CLASSIFICATION from Report 1 (page 32), as noted below.	**New tables and text added to the Introduction section**

TABLE 3.1 VEHICLE AND ENGINE CLASSIFICATION

Class	Vehicle	Diesel	Gasoline	Base Transmission
2b	Ram Pickup	Cummins 6.7 Liter 385 HP (base), 4.5 Liter 256 HP	3.5 L V-6, 6.2 L V-8	6-Speed Automatic
3				
4				
5	F-650 Tow Truck	Cummins 6.7 Liter 300 HP (base), 4.5 Liter 256 HP	3.5 L V-6, 6.2 L V-8	5-Speed Automatic
6	T270 Box Truck			
7				
8	T700 Tractor-Trailer	Detroit 14.8 L DD15 (base), 12.3 L Derivative	None	10-Speed AMT

Comment	Response
1.1 Present the major findings from Report 1 (list the technologies examined, highlight which technologies made it to this stage of the study);	**Paragraph added describing the content of Report 1,** but a full summary is out of scope.
1.1 Report 2 is a cost estimate study. It is not clear what role this has played in the down-selection process. If it has, please indicate how it did.	**New text added in Section 2.1**
1.2 Yes. The report has a brief but informative summary of the sections that follow.	**No changes required**
2.1 The section is well organized. Tables describe technology combinations for each engine and vehicle. This reviewer has checked the references between tables and descriptions. The report is very clear. There are only minor cases where there could be more clarity. Here may be one case: In some instances the report indicates the complexity of the packages assembled. Package 5 in page 16 is deemed very complex but it is not clearly indicated why. This particular package however may not be as complex however as packages 3, 3a, 3b… 3f that incorporate WHR. The report may want to capture the complexity of each of the packages (see suggestion below).	**Text added in all DD15 and T700 sections, plus all F-650, MD diesel, and MD gasoline sections**
2.1 The methodology is adequate. It is comprehensive and the work presented provides credible results. The systematic approach of stepping through "package" scenarios is very organized and easy to follow.	**No change required**
2.1 Please update and correct the following typos: - Table 2.7, 2.8, 2.9 have wrong reference to packages. o Table 2.7 P8: P2 + … should have been P7 + o Table 2.7 P9: P3 + … should have been P8 + o Table 2.8 P13: P2 + … should have been P12 + o Table 2.8 P15: P3 + … should have been P13 +, also +800 should be +700 o Table 2.9 P17: P2 + … should have been P17 + o Table 2.9 P20: P3 + … should have been P18 +	**Package references fixed throughout the text**
2.1 Page 10 states that cycles of Table 2.10 are described in detail Appendix C. This does not appear to be the case. The reader expects time traces of speed and load. Can these be inserted?	**Cycle descriptions and figures inserted in Appendix C**
2.1 Page 25 *2.3.5.9 3.5 V6 Package 18: Package 1 (should be 16) + Lean Burn (3.5 P18)*	**Fixed package references**
2.1 Page 26 *2.3.5.12 6.2 V8 Package 21: Package 1 (should be 20) + VVA (6.2 P21)*	**Fixed package references**

Comment	Response
2.1 Page 28, package numbers 2-5 seem mislabeled, they start at 11	These were checked, and they are correct. **No change to the text**
2.1 Page 35-36. Figure titles refer to F-650 *(should be T270)*	**Vehicle reference fixed**
2.1 Page 50. Reference made to F-650 in section *2.3.9.17 Comparison of the Three Baseline Engines in the F-650* need to be corrected *(should be Ram pickup truck)*	**Vehicle reference fixed**
2.1 Suggested improvements: The data may be rearranged to show more clearly the merit of each the technologies and the result of combinations. One way is illustrated in the figure below for the HD DD15 engine and the T700 vehicle, and later for the engines and F-650 vehicle. The tables seeks to: - Clearly highlight the technology content of each package and provide a better overview of the combinations, - Put a complexity weight factor for each package alongside the reported fuel benefit. Here GREEN=1, YELLOW=2, RED=3 (the designations are the reviewer's estimations and are inserted primarily for illustration purposes). - Charts may be drawn indicating the relation between the fuel and complexity index such as indicated below. - The tables are drawn for one of the drive cycles (NESCAFF for the HD and WHVC for the MD – each at 50% load).	The suggested table would provide a very useful summary of the technologies. Unfortunately, providing numerical evaluations of cost and complexity is out of scope for this project. **Descriptions of the cost and complexity challenges of each package have been added to the text**

Suggestions on analyzing HD simulation data

Results shown for NESCAFF – 50% load

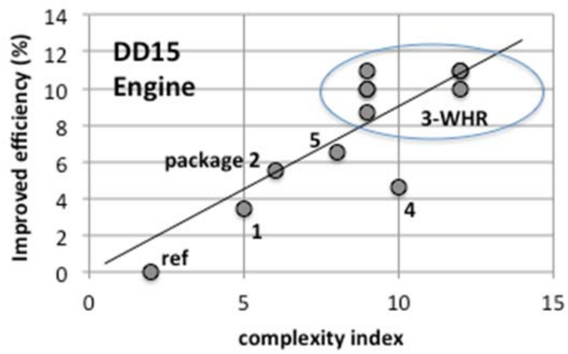
DD15 Engine Technologies in T700

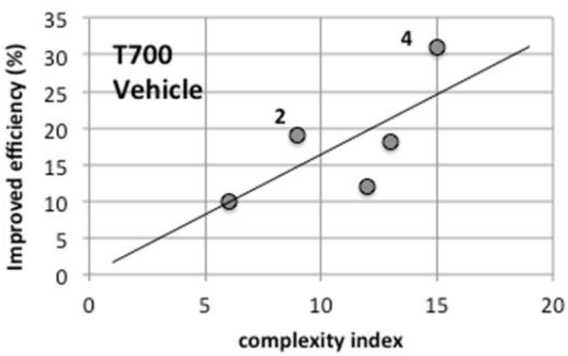
Package	Combustion	Turbocomp	Turbochg	EGR	SCR	flow restrict	FMEP	Downspeed	WHR	WHR-Recup	NESCAFF	Complexity
2011	-	base	Asymetric	base	base	base	base	1368			-2.4	
2019	1%	none	Asymetric	base	base	base	base	1368			0.0	2
1	1%	none	Asymetric	base	base	base	10-35%	1368			3.4	5
2	1%	none	Asymetric	base	base	base	5-17%	1051			5.5	6
3	1%	none	Asymetric	base	base	base	5-17%	1051	Water	-	10.0	9
3a	1%	none	Asymetric	base	base	base	5-17%	1051	R245	-	8.7	9
3b	1%	none	Asymetric	base	base	base	5-17%	1051	R245	x	10.0	12
3c	1%	none	Asymetric	base	base	base	5-17%	1051	MeOH	-	11.0	9
3d	1%	none	Asymetric	base	base	base	5-17%	1051	MeOH	x	11.0	12
3e	1%	none	Asymetric	base	base	base	5-17%	1051	EtOH	-	10.0	9
3f	1%	none	Asymetric	base	base	base	5-17%	1051	EtOH	x	11.0	12
4	1%	none	Fix	None	high Eff	base	10-35%	1368			4.6	10
5	1%	base	Asymetric	base	base	reduced	5-17%	1051			6.5	8

T700 Truck Technology Combination Results

	Cd	Crr	Weight	AC power	Chassis fric	Axles	Transm	Engine	SCR	WHR	NESCAFF	Complexity
	base	base	base	base	base	base	base	base	base	none	0.0	0
1	-15%	-10%	3%	base	base	base	base	base	base	none	9.9	6
2	-25%	-30%	-6.50%	base	base	base	base	base	base	none	19.0	9
3	-15%	-10%	3%	-40%	-20%	6x2	18-AMT	base	base	none	12.0	12
4	-25%	-30%	base	-40%	-20%	6x2	18-AMT	DD15-3b	base	install	31.0	15
5	-15%	-10%	3%	-40%	-20%	6x2	18-AMT	DD15-5	high eff	none	18.0	13

Comment	Response





Suggestions on analyzing MD simulation data

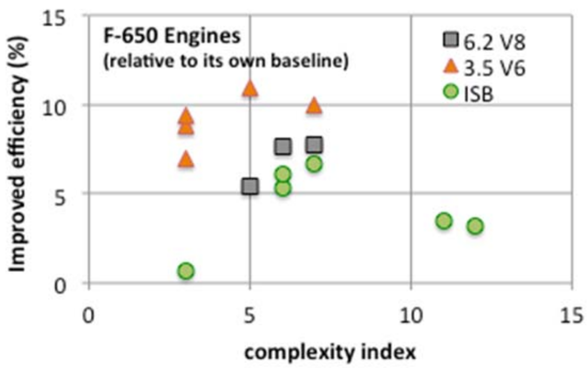
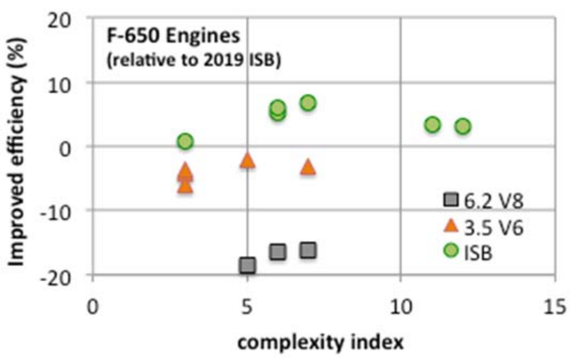
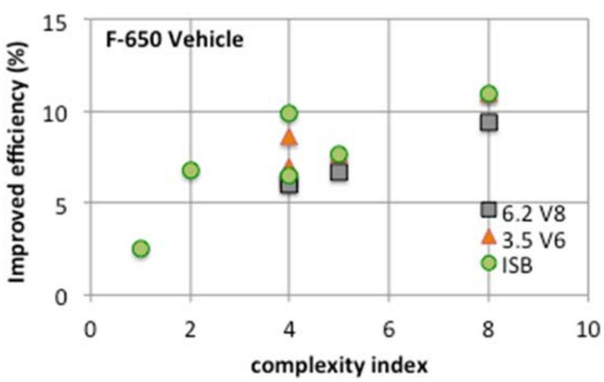
Results shown for WHVC – 50% load

F-650 Engine Technologies

Package	Engine	Combustion	Turbochg	EGR	SCR	VVA	Cyl Deactiv	FMEP	Downspeed	Downsize	WHVC-rel	WHVC-net	Complexity
2013	ISB	-	base	base	base	none	-	-	2500	-	-3.8	-3.8	
2019	ISB	1%	base	base	base	none	-	5-17.5%	2500	-	0.7	0.7	3
6	ISB	1%	2.5%	base	base	none	-	5-17.5%	2200	-	6.7	6.7	7
7	ISB	1%	5.0%	None	high eff	none	-	10-35%	2200	-	3.2	3.2	12
8	ISB	1%	5.0%	None	high eff	none	-	5-17.5%	2200	-	3.5	3.5	11
9	ISB	1%	2.5%	base	base	none	-	10-35%	2500	-	5.3	5.3	6
10	ISB*	1%	base*	base*	base*	none	-	base*	3000	4 cyl	6.1	6.1	6
16	3.5 V6	stoich	base	base EGR	-	VVA	-	-	5500	-	8.8	-4.2	3
17	3.5 V6	stoich	base	base EGR	-	VVA	-	-	4000	-	11.0	-2.0	5
18	3.5 V6	Lean	base	base EGR	-	-	-	-	5500	-	7.0	-6.0	3
19	3.5 V6	stoich	base	base EGR	-	-	-	-	4000	-	9.4	-3.6	3
20	3.5 V6	GDI	base	base EGR	-	-	Cyl Deactiv	10%	5500	-	10.0	-3.0	7
21	6.2 V8	GDI	base	base EGR	-	VVA	Cyl Deactiv	10%	5500	-	7.8	-16.2	7
22	6.2 V8	GDI	base	base EGR	-	2-Phasers		10%	5500	-	7.7	-16.3	6
23	6.2 V8	GDI	base	base EGR		-	Cyl Deactiv	-	5500	-	5.4	-18.6	5

F650 MD Truck Technology Combination Results

	Cd	Crr	Weight	AC power	Idle-N	Transm	ISB	3.5 V6	6.2 V8		WHVC		Complexity
	base	base	base	base	-	5-speed AT	0.0				0.0		0
11	15%	-			-	5-speed AT	2.5				2.5		1
11	-	30%			-	5-speed AT	6.8				6.8		2
12	-	20%				8-speed AT	6.5				6.5		4
		20%				8-speed AT		7.0			7.0		4
		20%				8-speed AT			6.2		6.2		4
13	-	20%			Idle-N	8-speed AT	7.7				7.7		5
		20%			Idle-N	8-speed AT		7.7			7.7		5
		20%			Idle-N	8-speed AT			6.7		6.7		5
14	-	20%				6-spd AMT	9.9				9.9		4
		20%				6-spd AMT		8.6			8.6		4
		20%				6-spd AMT			6.0		6.0		4
15	-	20%	700lb	40%	Idle-N	8-speed AT	11.0				11.0		8
	-	20%	700lb	40%	Idle-N	8-speed AT		11.0			11.0		8
	-	20%	700lb	40%	Idle-N	8-speed AT			9.4		9.4		8

Comment	Response
  	
2.2 Yes, overall the combinations chosen are well thought out. There is no "formal" justification for the packages, but this is reasonable as there are informative discussions imbedded in each package results discussion.	**No change required**
2.3 Yes, the cycles are appropriately chosen for each vehicle configuration.	**No change required**

Comment	Response
2.3 The cycles selected allow an understanding of how different engine and vehicle technology combinations perform across a range of applications through the drive cycle selection. The study considers too sensitivity to payload. The choice of 3 payloads provides sufficient resolution for weight impact.	**No change required**
2.3 The HD, MD T270 and F-650, and the Ram Pickup engine and vehicles use a different set of cycles given the nature of the application. The process is well thought out as shown in the Ram Pickup cycles. This category accounted for an empty truck, 50% of the maximum payload in the cargo bed (8,500 lbs) but no trailer (ALVW), and with trailer (25,000 lbs). The latter case accounts for the frontal area increased by 50% to account for the aerodynamic drag of the trailer.	**No change required**
2.3 Items that are unclear to this reviewer: - The choice of multiple WHR options seems disproportionate (e.g. multiple fluids). Overall 7 iterations are presented out of 11. They all point to the same conclusion (high efficiency). The discussion needs to consider the impact of fluids from the perspective of safety (EtOH, MeOH are highly flammable, water will have to cope with freezing). - On the other hand, only one turbocompounding option is presented.	Several WHR options were evaluated because they showed promise in Report #1, and because OEMs are exploring working fluids. **New text added in 2.3.2.4** Turbocompound did not perform well in Report #1, so only one version was evaluated in the technology combinations. No change to the text
2.4 The GT-POWER tools used are proven and widely used in the industry for engine modeling. The base models are calibrated with experimental data. The authors do a very nice job to include test heat release data, actual turbocharger maps (or scaled maps). EGR and AFR are controlled to match the baseline engine. The Appendices give comprehensive maps of the more important modeling parameters, including well resolved maps of the fuel consumption. Vehicles and vehicle technologies were modeled using SwRI's Vehicle Simulator, a proven tool. The Vehicle Simulator tool can handle the range of vehicle technologies studied here.	**No changes required**

Comment	Response
2.4 For clarity as a stand alone publication, Report 3 may want to include the definition of the term "Fuel Savings" (as was done in Report 1).	**Definition added in Summary and main body of report**
2.5 Yes. The report does a good job indicating the assumptions used and their rational. Some examples include: - Good description of the pumping work and its role in engine efficiency, - The distinction between FMEP (cylinder kit, bearing, valve train friction, fuel, oil, and water pumps, piston cooling nozzle) and accessory (not essential to engine operation such as AC compressor, alternator, power steering pump, air compressor, and engine cooling fan), - When presenting vehicle package P4, containing the DD15 P3b with WHR, the report is cautious to not add weight reduction, - The report notes the challenge of adapting existing SCR units on lean burn gasoline engine to reduce NOx owing to the large exhaust temperatures, - The modeling takes into account Idle-neutral features and the characteristics of the larger geared automatic s and the AMT transmissions. These are well documented in the Appendix.	**No changes required**
2.5 Clarifications needed: - Page 34, Engine Technology for the T270, "The same engine technology combinations have been evaluated in two different medium duty vocational trucks" seems redundant given the previous statement before it and it reads like there is two T270 trucks under study. - Page 37-38. The comparison between the T270and F-650 is very useful. The discussion on the ISB is very clear, but no so with the V6 and V8 engines. The text regarding the rich-operation (it is stated to be more efficient) is not expected.	**Text clarified in Section 2.3.7** **Text clarified in Section 2.3.7.1**

Comment	Response
2.5 There is a potential source of confusion in the results for the **MD Vocational Truck and the Pickup Truck Engine and Vehicle Technology Combinations**. Results are shown in terms of percent fuel consumption reduction compared to each engine's baseline projected 2019 configuration. - In addition to the benchmarks provided, **results would be more useful if expressed in % fuel savings with respect to one common reference.** This is done only briefly in the conclusion for a brief sample of the cases considered. *The report does addresses the differences between baseline engines, such as in Figure 2.7. The dependence on cycles is shown at 50% payload. Here shows that the V6 gains approximately 11% (varies with cycle) and the ISB gains approximately 24% (varies with cycle) over the V8 baseline.*	Adding a comparison of each package's performance against a common baseline in addition to its own baseline would require extensive new text and figures. **No change**
- The report uses the "ISB 2019" as baseline for the technology comparison. This effectively means that the V6 entries (P16-P19) and V8 entries (P20-P24) have a 13% and 24% fuel deficit respectively. *The report does indicate that Diesel has a 13% fuel consumption advantage over the gasoline engine due to the energy differences for the same volume.*	**No change required**
- Overall, comparing to one same reference would add clarity.	**See above response**
- Costs, durability, need be considered such as with an efficiency vs. cost tradeoff.	There is text describing cost and durability issues. **No change to the text**
2.5 ISB package 10 is difficult to follow. The downsizing, remake of the lug line of the engine, and the vehicle axle ratio modifications makes this entry significantly different than the others. This same package retains EGR.	**New text added in Section 2.3.5.6**
2.5 Same ISB package 10 could have considered SCR.	This would require another technology combination, which is out of scope. **No change**

Comment	Response
2.6 Yes. The findings are highly coupled to the simulation work performed. - The report does a good job to tie in the work and performance results from the Supertruck program when considering the more technologically aggressive packages on the T700 vehicle. - There are some very good insights in the report that may not be readily known: o The downspeed option (ISBP 6 and ISB P8) show a slight and rather large fuel penalty on the CARB and Parcel drive cycles. The report indicates that the higher torques at lower rated speeds will require tighter torque match to reduce the fuel requirement when vehicle is stationary.	**No change required**
2.6 This reviewer found the comparison section *2.3.7.1 Comparison of engine technology results between the T270 and F-650* particularly useful as it provided a good summary of the technologies and how they related to the results found in the report.	**No change required**
2.6 Suggestions: - The "state-of-the market" discussion on *2.3.11 Hybrid System Results* is brief but informative. The results of the simulation (performed by Argonne) is shown. Further discussion may place these results in the context of the engine and vehicle: asses at least qualitatively if not quantitatively the efficiency vs. cost/complexity that this option provides; highlight barriers to overcome the poor payback and the technical challenges to migrate the technology to the MD-HD sector.	**New text added in Section 2.3.11**
2.6 Clarifications needed: - In section *2.3.2.12 DD15 Technology Package 5: Packaging the reduced restriction intake, exhaust, and charge air cooler systems in a practical vehicle would prove very difficult*. Please explain why.	**Text added in Section 2.3.2.12**
3.1 The study selects aerodynamic drag coefficient (Cd), tire rolling resistance coefficient (Crr), axle ratio and vehicle empty weight as the parameters for study. This section focuses on single parameter sweeps, unlike the earlier section that focuses on combination technology packages. These parameters are important for the MD vehicle performance.	**No change required**

Comment	Response
3.1 Section 3 could be enhanced by: - Indicating that the results in Sect 3.1 (aerodynamic sweep) may be referenced to Section 2. The results for Fig 3.1 were presented in page 52 for P16, for Fig 3.2 in page 29 for P11 , and for Fig 3.3 in page 39 for P6. - Improve consistency in the report: Package P16 is noted in Fig 3.1, but P11 and P6 are not in the following Fig 3.2 and 3.3. - Improve consistency in the report: Table 3.1 lists the max percent grade in top gear, even when downshifted take place. The following Tables 3.2, 3.3 don't. Similarly Table 3.2 shows Gear Bound entries, but Table 3.3 does not (ISB 6.89 AR entry). - Providing a summary on the overall contribution of aero, rolling resistance, AR and weight that compare one with respect to the others.	**Text added in Section 3.1** **Figures relabeled** **Tables updated** **New Section 3.7 added**
3.1 Typos and possible corrections: - Page 59-63. The results for **Cd and Crr sweeps** as shown in the figures appear to scale (the relative size of the Fuel Savings bars are same across cycles as the sweep takes place). This seems to imply that Cd or Crr impacts on vehicle drag and friction does not change across drive cycles (but these have wide ranges of speeds and accelerations). Could these results be checked? - Page 62. On the F-650 and T270 trucks, the largest fuel savings comes at 55 MPH, with the second largest benefit at 65 MPH (figures show it is WHC instead – though most cycles are relative same with exception of the Parcel). - Page 65 Fig 3.10, title Ram P2 (should it be P17).	The Cd and Crr sweeps do scale, although by different amounts, depending on drive cycle. **No change** **Text under Fig. 3.6 modified** **Figure headings for 3.10, 3.11, and 3.12 corrected**
3.2 The ranges are appropriate.	**No change required**
3.2 Suggestions: - The report could gain if it provided a short description on what features would be responsible for the magnitude of the sweeps. For example, Cd% reduction range per each vehicle category (roof deflectors, fuel tank fairings, box skirts, mirrors). Same could be done for Crr% reduction. Maybe a reference could be inserted here such as ***Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles (National Academies Press, Jul 30, 2010).*** Similarly, a justification for the weight reduction quantities can be given. - The results presented under the Ram Axle Ratio Sweep, when comparing the engine configurations, adjusts the gasoline engine axle ratios to a shorter setting (higher AR value) to match the towing capability. However, the figures in the section represent simulations at ALVW (much lower load). *This may be okay as tater in the section, the study takes up the effect of AR on grade performance, and here the effect of AR is seen at the higher payload - GCW.*	**New text added in Section 3.1** Gasoline engines need a shorter axle just to get a high GCW rating, regardless of actual payload. **No change to the text**

Comment	Response
3.3 Yes, the vehicles and engines chosen were appropriate.	**No change required**
3.4 The results are reasonable. The methodology used in the simulation follows the same approach as in Section 2. Results are well organized and discussed.	**No change required**
3.4 Section 3 highlights or re-emphasizes what may be an important question for future regulations: - The fuel economy gains for individual technologies are very dependent on the drive cycles. - How can the regulatory body and manufacturers work to better align regulatory cycles to real-world applications and thus encourage technology packages such as the ones discussed in the Report?	**No change required**
4.1 This section [4] focuses on the overall merits of Diesel vs. gasoline fueled engines in the vocational sector. The section provides a brief and informative description of the Diesel and gasoline presence in the MD market since 1994. Important shifts are highlighted, such as the large price differential between the Diesel and gasoline exhaust after-treatment devices. The cost added of the Diesel option on F-650 is revealing, and is explained with the added aftertreatment devices, fuel injection system and base engine.	**No change required**
4.1 Fuel consumption benchmarks are provided for the T270 vehicle for the baseline Diesel engine and a selected technology package for the V6 and V8 gasoline engines. *The report could also make reference to the baseline engine comparison provided in Section 2 for the F-650 (Fig 2.7, page 28).* The analysis then continues to examine a payback analysis and results are summarized in Table 4.2. Overall the presentation is clear and informative. The analysis makes a powerful case for gasoline, unless the Diesel engine can contain the cost differential.	**Payback times for the baseline V-8 added to Table 4.2, and new text added**

<table>
<tr><th>Comment</th><th>Response</th></tr>
<tr><td>4.1 The discussion on vehicle specifications is limited to a brief discussion on vehicle power demand and a review of the aero, rolling resistance and weight analysis from Section 3. The Charter indicates that a comprehensive “specification sheet” be drawn up. One interpretation is a table with one dimension describing specifications and the other attributes. This work can be of considerable magnitude and may be beyond the scope of the current Report. Nonetheless, the interpretation may be to provide a table as shown below, where for weight the technology specification may be highlighted given the vehicle specification.

Sample of “effect of vehicle specification”
<table>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Vehicle features</td><td colspan="4">Engine features</td></tr>
<tr><td>Requirements</td><td>PWR/TQ</td><td>Axle Ratio</td><td>Body (Style)</td><td>Frame (Weight)</td><td>Transmission</td><td>Fuel Type</td><td>Aero</td><td>Crr</td><td>Idle Neutral</td><td>…</td><td>FMEP</td><td>Cyl Deactivation</td><td>VVA</td><td>Downspeed</td></tr>
<tr><td>Towing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Grade</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Distance travel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Drive Cycle</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maneuverability</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Visibility</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>…</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
</td><td>This discussion would be a useful addition to the project, but is out of scope. No change</td></tr>
<tr><td>4.2 The assumptions made for the payback analysis are adequate. The assumptions include reasonable ranges for the baseline cost of gasoline fuel and the cost differential between gasoline and Diesel. Though not clearly specified, there is reference to the life of the vehicle which helps frame the payback results (12-15 years).</td><td>No change required</td></tr>
<tr><td>5.1 This survey is very informative. The report on natural gas begins with a clear motivation of lower fuel price, lower carbon content leading to lower GHG emissions, and government subsidies.</td><td>No change required</td></tr>
<tr><td>5.1 It may be noted that many municipalities are requiring NG vehicles (in some cases they require from a manufacturer a percent of vehicles to be purchased be NG).</td><td>Text added in 3rd paragraph of Section 5.0</td></tr>
</table>

Comment	Response
5.1 The report outlines important issues regarding the adoption of natural gas vehicles. *These issues are very important. One personal experience in this area entails following the introduction of natural gas buses in a major municipality in Europe – today operating over 900 natural gas buses in addition to 1200 Diesel buses. The municipality took several years to attain "smooth running". Many of the issues they struggled with are contained in this Section. One issues not mentioned in the report that could be included is safety – in this municipality, the use of natural gas vehicles was restricted to operate above ground. All bus routes that used tunnels were assigned to Diesel buses.*	**Text on underground and tunnel operations added**
5.1 The report could also include estimates of fill in times. *These may be 25 GGE/hr (with 58 SCFM IR compressor) and up to 50 with accumulator-equipped stations (per experience from 2010-2012 time frame).*	**Added reference to a DOE report on fueling infrastructure costs and capacity in Section 5.1**
5.2 Yes, the survey appears accurate. It is comprehensive and well explained.	**No change required**
5.2 The sensitivity of pump prices to raw fuel prices from Table 5.7 seemed surprising, specifically the higher % increases for gasoline and Diesel vs. natural gas, but the numbers check. It highlights the impact of a low base cost for the natural gas fuel.	**No change required**
5.2 The reporting fuel efficiency by Paper Transport and Kroger are important "real-life" reference data.	**No change required**
5.2 *It may be worth inserting these vehicle configurations on the SWRI model tool to study the breakdown of the losses. The natural gas vehicles are reported as having less aerodynamic profiles, weight increase and worse than Diesel efficiency. This could be a good "case study" to be included in the report.*	Good idea, but beyond the project scope. **No change**
6.1 Conclusions should identify technology segments for regulators, OEMs, Tier I suppliers, and in general consumers that will positively impact fuel savings while meeting current or future emissions standards. The conclusions, at least should point to specific technologies that merit further investigation. The report does this.	**No change required**
6.1 Conclusions appear they could be more focused. The authors may want to see if they can be made more specific, possibly more systematic, breaking them down by category, and including some evaluation regarding the complexity or risk (such as indicated earlier in Section 2).	**The conclusions section has been replaced by most of the original ES**

Comment	Response
6.2 Tables 6.1 and 6.2 are rather difficult to follow. - Section 2 focuses on % savings with respect to each engine baseline. - Here we have a comparison of the gasoline engines with respect to the Diesel. The numbers should readily come out from the previous tabulated results but they don't. I would strongly suggest that this be done: reference what tables in Section 2 are used to obtained the numbers shown.	**New text added under Table 4.1**
6.3 The Conclusion Section lacks a description of synergies among technologies. Conclusions could include what technologies work well with one another, and which do not. This was emphasized in the Charter and would be important to include.	**Several subsections on technology synergy have been added**
6.3 The report establishes other fuel savings opportunities that were not able to be included in Report 3, such as reduced cooling fan power demand and improved efficiency of engine driven accessories such as hydraulic systems. It is good that this be pointed out and hopefully can be taken up in the future in a similar study.	**No change required**
6.3 Fuel savings are highly dependent on duty cycles. The report makes a strong case that vehicle and engines need to be well matched given the application. As in the case of the pick-up market, the installation of the 385 HP and 850 lb-ft Diesel engine is not needed unless trucks operate near GCW – whence it is important. The use of the downsized V6 provides significant fuel savings.	**No change required**
7.1 Yes. They [the appendices] provide very good technical background to the sections of the report both for engine and vehicle (which includes a strong section on axle, governor speed and engine alternatives), and hybrid technologies.	**No change required**
8.1 The report is very well organized, it reads well and is clear. - The simulation of combined technologies is very complete. The report relies on a strong and systematic modeling approach, - The cycles, vehicle, and engines chosen are very representative and adequate to fulfill the task.	**No change required**
8.2 Yes, the report is technically very detailed and is accompanied by informative Appendices.	**No change required**
8.2 The addition of the following items may strengthen the report: - Incorporate a summary of GHG Emission and Fuel Efficiency standards, - Fuel saving estimates complemented with a cost-risk "complexity index", - The Conclusion Section should detailed the sources for the results shown on Tables 6.1 and 6.2.	These issues were resolved in comments above. **No additional changes**

Comment	Response
8.3 The simulation, technology-packages description and discussions are very strong. - The cycles selected highlight how different engine and vehicle technology combinations perform across a range of applications. Results illustrate how some technologies are sensitive to payload in a given drive cycle, - The report clearly indicates and justifies the assumptions used, - The findings are well aligned to the simulations, - The payback study is very informative and the analysis makes a powerful case for gasoline, unless the Diesel engine can contain the cost differential.	**No change required**
8.3 The reporting of fuel savings is mainly done with respect to each engine baseline. This is reasonable given the unique characteristics of each platform. Nevertheless it would seem necessary to compare each engine platform in the case of the MD and Pickup sector.	This issues was resolved in the comments above. **No additional changes**
8.4 The discussion on vehicle specifications (Section 4) is limited. The charter indicates the need of a comprehensive "specification sheet" be examined for the MD sector. It may be worth attempting to sketch this, possibly along the lines of the table shown in the commentary of Section 4 above.	Beyond project scope. **No change**
9.1 I find the report acceptable with minor revisions.	**No change required**
9.1 The report presents an excellent simulation study throughout a very comprehensive list of combinations for engine and vehicle technologies. It is very informative.	**No change required**
9.1 Minor revisions requested are: 1. Correct typos as indicated in this charter revision (see earlier sections) 2. Update Conclusions to specify more systematically a breakdown of fuel savings per category, including evaluation regarding the complexity or risk. 3. Clarify how the entries on Table 6.1 and 6.2 were calculated. Given that the comparison approach differs from the earlier section, please show how they are estimated based on the results from Section 2.	These issues have been addressed in the above comments. **No additional changes**

Final Report #2

Shawn Midlam-Mohler Reviewer Comments and Responses

Comment	Response
1.1 The report provides a sufficient overview of Report #1 and the overall program. There is no reference to Report #2 that I could find (e.g. searching for '#2' or 'second' yields no hits.)	**Reference to the cost report added**
1.2 **Does the introduction adequately detail the report contents?** Yes.	**No change required**
2.1 Weight was discussed specifically as a non-additive feature of some of the technologies used. Other than that, there was not a consistent and explicit discussion of if the technologies were additive or not. This could be done if the impact of individual technologies were assumed to be completely additive – one could then compare to the simulated results with the technologies deployed in a single simulation. Technology packages which outperformed the individual summation of technologies are synergistic, technology packages which did about the same are additive, technology packages which were much less interfere with each other. This could possibly be done on a 'meta' level looking at results from this study and that from Report #1.	**Several subsections added to Section 2 on synergy or lack of it: 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18**
2.1 Assumptions are often made and could be documented better. Once can search for the word 'assume' throughout and find many examples that could be better documented. For instance, source of assumption for "For 2019 baseline diesel engines, an assumption was made that there would be a 1% efficiency improvement due to combustion system development." in 2.1.1 – what is this assumption based on?	**Section 2.1.1 revised**
2.1 The vehicle simulation approach uses well-known simulation packages and is believed to be appropriate for the type of analysis conducted.	**No change required**
2.1 Regarding this: "Because WHR systems have very slow transient response, they do not contribute much useful work on highly transient cycles." I agree that the first half of the statement is accurate but not the second. If there is a cycle with a high average heat rejection that is transient a WHR system can still do well. I think this needs to be re-evaluated – assuming that a WHR system produces nothing on certain cycles is because they are 'transient' is not well supported by the report. It may be true, but it is a large assumption that is not backed up.	**Text on WHR revised and expanded**
2.1 Regarding the GT-Power simulations, the details of this were presented and peer-reviewed in Report #1. I made a quick review of this but given that this was the subject of the Report #1 and there are little technical details in this report I am not providing specific comments.	**No change required**
2.1 The methodology section (2.2) could be enhanced some more with a particular focus on the approach used to validate the engine technologies. Many of the technologies simulated were	**New text added in 1st paragraph of Section 2.2**

extrapolations off of existing technology so a robust validation was not possible – that is quite relevant given the purpose of the report. Much of this was covered in Report #1 – but this should be emphasized here to provide good context for the work under review.	
2.2 The approach used to select the select the combinations is not clear. For instance, why is the "1% combustion efficiency improvement" and "FMEP reduction" not applied to vehicles with the bottoming cycle in the DD15 scenarios? I don't see why these technologies would necessarily not work together. I realize that one can't simulate every permutation but it is unclear what process was used. I would recommend clearly defining how these packages were arrived at.	The existing text explains that the 1% combustion improvement was included in the WHR scenarios, and that FMEP reduction was not included because of increased BMEP from downspeeding. **No change**
2.2 This information could also be communicated more clearly than the tabular form used.	Data is presented both in tables and graphs. **Tables and text modified to improve clarity**
2.3 I believe that that vehicles were representative. This could be backed up further with fleet data demonstrating the prevalence of these classes of vehicles in the US fleet. I believe that the drive cycles were appropriate.	**No changes required**
2.4 The vehicle models were appropriate The engine modeling approach was appropriate and good judgment was used in accommodating for the weaknesses is this type of tool. (See previous comment about enhancing the discussion on validation of models.) For the WHR system, see earlier comment regarding transient modeling.	**No changes required**
2.5 There were no assumptions that I found to be unreasonable. However, there are many assumptions that are not referenced to any sort of supporting material. For the majority of these assumptions there exist publications that could be easily references to support the assumed value. I think this should be done in this document – otherwise it is unclear to the public that this number is valid.	**Text of Section 2.1.1 revised**
2.6 I feel that the findings are supported by the data. The key to a simulation like this is to have well-vetted input data to the simulation. Most of the input data for this simulation was presented in Report #1. I feel the process used here is straightforward (although very technical and time consuming to execute…) and that the inputs are really what is driving the results.	**No changes required**

2.6 I feel that this section would benefit from a 'summary of the summaries" so to speak. Right now there is a tremendous number of tables and figures showing data. At the end of the section, it would be powerful to somehow do a weighted average (or just straight average) of the different cycles and provide a few simplified figures. Another suggestion might be reporting on the min/mean/max/std of the technologies deployed to give an idea of how much variation there is. This would also facilitate comparing between the classes of vehicles. It might also be helpful to pull out technology packages that were identical (or similar) across vehicle classes to show how they change across class.	**Moved most of the original ES to replace the original Section 6, and moved most of Section 6 up front to form a more concise ES**
2.6 I have no other specific recommendation other than those that were included above.	**No changes required**
3.1 Yes, this the selection covers the main factors at the vehicle level	**No changes required**
3.2 Yes – however – there should be citations demonstrating that the chosen ranges are span what is believed to be technically achievable over the relevant time period.	**New text added in Section 3.1**
3.3 **Were the vehicles and engines used in the parameters sweeps appropriate?** Yes.	**No changes required**
3.4 The majority of the simulation results show consistent and the expected trends. There are a few (see Figure 3.18) that are demonstrate some unusual behaviors. The simulations to do this are fairly straightforward, so it should be easy to isolate and describe why the behavior of these cases (e.g. CILCC below) is so strange. Overall there is great detail on the vehicle/engine models – but something like an inappropriate shift schedule could lead to this type of unusual behavior. It could be that there is a good explanation of these behaviors – but without that being discussed sufficiently it casts some doubt onto the approach.	**New text added under Figure 3.18 to explain the anomaly**
4.1 Overall this section is not as extensively researched or as comprehensive as the previous section. The discussion is relevant but could be more robust and comprehensive.	Requested change is beyond project scope. **No change**
4.2 The $9000 assumption for the difference between a diesel and gasoline system needs to be documented. A higher-tech gasoline engine comes with some increase in price (boosting, GDI, etc.) GDI engines may also require particulate matter control in this class of vehicle as well – there is talk of this in the light-duty market based on new regulations.	**Text added to explain the $9000 assumption**
4.2 Need basis for 25,000 miles per year traveled assumption – or make this a parameter that is varied. The time-value of money is neglected in the payback analysis. Taking this into account is simple and should be included.	**Text and table revised to use FHWA VMT figures (13,116 miles per year in 2013)**

4.2 Payback periods beyond a certain max vehicle life should be labeled 'Never' in Table 4.2. A 30 year payback period is not really relevant.	**Table 4.2 and text modified to label payback times >20 years as ">Life"**
4.2 Results from Table 4.2 would be easier to view as a figure.	Beyond project scope, so **no change**
5.1 Yes, this seems to be a solid review of the market with relevant discussions. Note: I do not have deep experience with commercial CNG in the heavy-duty market. Much of this is related to current market trends and offerings.	**No change required**
5.2 I did not find any errors or omissions and felt explanations were good. See note above in 5-1.	**No change required**
6.1 The summary does a good job at highlighting Section 2 but does not highlight results from Sections 3, 4, and 5.	**New subsections added to cover Sections 3, 4, and 5**
6.2 **Did this section effectively present overall conclusions?** Yes – with the caveat from 6-1.	**No change required**
6.3 **Are any important conclusions missing or inadequately explained?** No – with the caveat from 6-1.	**No change required**
7.1 As described previously, the Appendices provide information on the inputs to the modeling approach – but not much detail on how the technology maps were derived. I think this is OK as that is described in detail in Report #1 which was peer reviewed as well.	**Additional material added to appendices**
8.1 Section 2 is very, very figure/table dense. To the point that it is very difficult to make high-level conclusions. As stated previously, providing some summary plots of the data that consolidate results into a single figure would be helpful.	After review, decided not to increase duplication between report sections. **No change**
8.2 Yes [information is sufficiently detailed]. See earlier comments.	**No change required**
8.3 The weakest part is Section 4 and Section 3. Section 4 is a simple analysis (which is OK) but assumptions are not well documented and it is not a very complete analysis (see comments.) Section 3 could also use additional explanation regarding some of the curves (see comments.)	**Responses to these comments are provided above**
8.3 A lot of work went into Section 2 – this is definitely the most technically strong portion of the report.	**No change required**
8.4 No additional comments.	**No change required**

Final Report #2
Dana Lowell Reviewer Comments and Responses

Comment	Response
1.1 Yes, section 1 provides sufficient background for this report to be read as a stand-alone document	**No change required**
1.2 Yes, the introduction adequately describes the report contents	**No change required**
2.1 The methodology used for this analysis was rigorous and appropriate for the aims of the project. It was also comprehensive enough to provide credible results.	**No change required**
2.1 In general the methodology was clearly described, but there could have been more context provided for why some specific combinations of engine and/or vehicle technology were chosen. In many cases the logic is clear, in others it is not. For example, it is not completely clear why DD15 engine package 3b was chosen for vehicle technology package 4 (T700) or why DD15 engine package 5 was chosen for vehicle technology package 5 (T700) – as opposed to one of the other engine technology packages.	**New text added to the first paragraph of Section 2.1**
2.1 The charge says that part of the purpose of this project was to evaluate the additive nature and synergistic relationships between different options for fuel economy improvement. To that end the authors did explore combinations of both engine and vehicle improvements for the T700 truck (vehicle technology packages 4 and 5). However, they did not do so for any of the other trucks; for the F650, T270, and Ram Pickup the vehicle technology packages included only the baseline engines – no packages included any of the modeled advanced engine packages. The reason why engine/vehicle synergies were only explored for the T700 and not the other trucks should be explained and justified.	**Several subsections added on synergy or lack of it in Section 2. See 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18**
2.2 The technologies selected for the different combinations that were analyzed were appropriate and logical.	**No change required**
2.2 The charge says that part of the purpose of this project was to evaluate the additive nature and synergistic relationships between different options for fuel economy improvement. To that end the authors did explore combinations of both engine and vehicle improvements for the T700 truck (vehicle technology packages 4 and 5). However, they did not do so for any of the other trucks; for the F650, T270, and Ram Pickup the vehicle technology packages included only the baseline engines – no packages included any of the modeled advanced engine packages. The reason why engine/vehicle synergies were only explored for the T700 and not the other trucks should be explained and justified.	**Several subsections added on synergy or lack of it in Section 2. See 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18**
2.3 Yes, the vehicles and drive cycles used in this study were appropriate to the task of evaluating Class 2b-8 fuel consumption performance.	**No change required**

Comment	Response
2.3 The only way in which the chosen vehicles and drive cycles do not adequately cover the full range of Class 2b-8 vehicles is that they do not address vocational vehicles with significant engine-driven vocational loads – for example refuse trucks (hydraulic packer), cement mixers, utility trucks (aerials), etc. That being said, these vehicles likely represent a very small percentage of total fleet-wide fuel use, so incomplete coverage of these vehicles in this project will not significantly reduce the value of the results.	Engine driven accessories were out of scope. Very little data is available on vocational truck accessory power demand. **No change**
2.4 This is not my area of expertise, but given my limited knowledge it appears that the computer models chosen were appropriate to the task and applied correctly. I believe that there is adequate description and discussion of the models, their limitations, and the assumptions used, for informed readers to make appropriate judgements about the accuracy and utility of the results.	**No change required**
2.5 Yes, the assumptions used in the analysis are reasonable.	**No change required**
2.6 The findings and conclusions of this section are adequately supported by the data This section could be improved in the following ways. These suggestions are primarily designed to improve the readability of the report and to help the reader more easily understand the interconnections and implications of the data presented:	**No change required**
• In section 2.2, pages 10 – 11, when discussing the different drive cycles used in the analysis, for each drive cycle the authors should indicate the relative amount of engine load imposed by the cycle (low to high). In Table 2.10 the individual drive cycles should be listed in order of low to high engine load from left to right.	Beyond project scope. **No change**
• For all of the tables and figures in Section 2, the results should be consistently shown with the different drive cycles in order of low to high engine load from left to right – i.e. for Figure 2.1 the order from left to right should be WHVC, CARB, 55 MPH, 65 MPH, NESCCAF, rather than the order in the existing figures. This would allow the reader to more easily see the relationship between the fuel economy results and the relative severity (engine load) of the duty cycle, which for many of the technologies appears to be fairly consistent.	Beyond project scope. **No change**
• For all of the tables and figures in Section 2, in addition to results for the individual drive cycles the authors should also show results for a weighted average of the CARB, 55 MPH, and 65 MPH cycles, as currently used in GEM for certification under NHTSA/EPA Phase 1. This would more easily allow the reader to put these results into the context of existing regulations and therefore judge how they might apply to future regulations.	Beyond project scope. **No change**

Comment	Response
• In tables 2.2, 2.3, 2.4, and 2.5, for the description of the engine and vehicle technology packages the authors are not consistent in how they number each package, which is confusing. For example, in Table 2.2 which describes engine packages for the ISB medium-duty engine the notes for Package 9 say: "Compare to package 1", but Package 1 is not an engine package for the ISB medium-duty engine, it is an engine package for the DD15 heavy-duty engine (Table 2.1). For Package 9 the note should say "Compare to Package 6" (the first package for the ISB engine in Table 2.2). There are numerous other similar examples that should be corrected because it is confusing as written.	**Package numbers and references are fixed**
• For all tables in this section, every number in a given table should be shown with the same number of significant digits (i.e. if numbers less than 10 are shown with one significant digit (2.0) then numbers greater than 10 should be shown with one significant digit as well (10.0, not 10)	The number 2.0 has two significant digits, as does the number 11. **No change**
• In Section 2.3.2.10 there appears to be a mistake. The text says: "The overall fuel savings performance of the P3f system is similar to that of the P3d Ethanol + recuperator system." I believe that this sentence should say "The overall fuel savings performance of the P3f system is similar to that of P3d Methanol, + recuperator system".	**Error corrected in Section 2.3.2.10**
• The fact that this section directly compares in the same tables and figures the "Fuel Savings %" for different configurations of diesel and gasoline engines, with Fuel Savings denoted in gallons, is somewhat mis-leading to the reader. The text does note the fact that diesel has 13% more energy per gallon than gasoline, but it is hard for the reader to translate this information so as to compare the gasoline and diesel engine options on an energy equivalent basis. In addition to the existing tables and charts, the report should include figures which directly compare the modeled gasoline and diesel engine options on an energy-equivalent basis. There are several option for doing this, all of which would be essentially equivalent; one could plot the % reduction in btu/mi or btu/cycle, or one could plot the % reduction in gasoline-gallon equivalents (GGE) per mile or GGE/cycle. Alternatively, one could plot the % reduction in carbon dioxide (CO_2) emissions per mile or per cycle. This option would be appropriate given that this report is in support of joint NHTSA/EPA rulemaking that will set fuel economy and GHG emission standards. At a minimum this information should be added to sections 2.3.5.16, 2.3.7.1, and 2.3.9.17.	Beyond project scope. **No change**
• It is hard for the reader to evaluate whether the range of aerodynamic drag and rolling resistance reductions included in the T700 vehicle packages (15%, 25% C_d reduction; 10%, 30% C_{rr} reduction) was	**New text added to 1st paragraph of Section 2.3.3**

Comment	Response
reasonable, because there is no discussion in the document of what types of changes might be required to the baseline truck in order to achieve this level of reduction. For example, photos of the Kenworth T700 show that it has a very aerodynamic shape. What changes to the T700 cab and/or standard trailer would be required to reduce the combined C_d by 25%? What specific model of tire was assumed for the baseline T700 and why? Are there commercially available tires for this truck that would reduce C_{rr} by 30% compared to the baseline tire? Providing this information, along with a photo of the baseline truck and trailer that was modeled, would allow the reader to better put the data in this report into the proper context.	
3.1 Yes, the parameters chosen for the sweeps represent a realistic and comprehensive range of vehicle characteristics that could affect fuel use for medium-duty vehicles.	**No change required**
3.2 For aerodynamic drag it is difficult for the reader to evaluate whether the range used in the sweeps was appropriate because there is no discussion in the document of what types of changes might be required to the baseline trucks that were modeled in order to achieve this level of reduction. For example, photos of the Kenworth T270 show that it has a somewhat aerodynamic shape, but not as aerodynamic as the Kenworth T700, for example. Would changes to the T270 cab to make it look like the T700 cab reduce C_d by 10%? What more would be required to reduce C_d by 20% or 30% (i.e. rounded top and corners for box body, roof fairing between top of cab and top of box, side fairing between side of cab and side of box, other?). Photos of the baseline vehicles, and discussions of the types of changes required to achieve 10%, 20%, and 30% reduction in C_d would be very helpful to the reader to put the results of the aerodynamic sweeps into the proper context.	**New text added to 1st paragraph of Section 2.3.3**
3.2 For rolling resistance it is difficult for the reader to evaluate whether the range used in the sweeps was appropriate because there is no discussion in the document of what types of changes might be required to the baseline trucks that were modeled in order to achieve this level of reduction. For example, what specific model of tire was assumed for the baseline trucks and why? Are there currently commercially available tires for these specific vehicles that would reduce rolling resistance compared to the baseline tire by 10%, 20%, and 30%? Including this type of discussion in the document would be very helpful to the reader to put the results of the rolling resistance sweeps into the proper context.	**New text added to 1st paragraph of Section 2.3.3**
3.2 The ranges for the weight and axle ratio sweeps are appropriate.	**No change required**
3.3 Yes, the vehicles and engines used in the parameter sweeps were appropriate	**No change required**
3.4 Yes, the results of the parameter sweeps are plausible	**No change required**

Comment	Response
4.1 **Are the discussions accurate and relevant to the subject matter?** Yes.	**No change required**
4.2 All of the assumptions used in the payback analysis are appropriate except annual miles per truck, which appear to be quite conservative (high). Edition 33 of the Transportation Energy Data Book indicates that in 2012 the average annual miles driven by Class 3 – 8 single unit trucks was 12,816 miles (Table 5.2). It is therefore not clear why the authors chose to use 25,000 miles per year in the payback analysis. The use of a larger assumption for annual miles reduces the payback period for diesel trucks relative to advanced gasoline trucks – as such the author's analysis is quite conservative – for the "average" truck owner the payback periods would in fact be significantly longer than those shown, providing even greater incentive to switch to gasoline medium-duty trucks.	**Section 4.1 and Table 4.2 revised to use FHWA VMT estimate of 13,116 miles per year**
5.1 The initial discussions about natural gas engines and natural gas storage systems are appropriate and for the most part accurate – see below for areas that require further elaboration	**No change required**
5.2 In section 5.1, page 84 it is noted that "if a CNG tank is filled rapidly, usable capacity is reduced by about 20%. Only a slow (typically overnight) fill will get the tank to full capacity". I do not believe that this is an accurate statement. It is typical and acceptable for fast-fill CNG stations to use a temperature compensated fill algorithm to allow up to 4,500 psi in the cylinder at the end of fueling, as long as the "settled pressure" once the gas and cylinder has cooled to 70 degrees F would be no more than 3,600 psi (see, for example http://www.afdc.energy.gov/bulletins/2014_09_18_CNG_Temp.html). With proper temperature compensation even fast-fill stations should be able to fill a tank to greater than 80% rated capacity.	**Revised text and new reference added in Section 5.1**

Comment	Response
5.2 I believe that section 5.4 (natural gas prices) would benefit from a longer-term historical comparison of natural gas versus diesel price trends. US DOE Clean Cities has been issuing quarterly reports on natural gas and diesel fuel prices at public fuel stations since May 2000 (http://www.afdc.energy.gov/publications/search/keyword/?q=alternative%20fuel%20price%20report) and this data could be used to provide this historical perspective. The salient point that would be gained from this comparison is that prior to 2008 natural gas was generally more expensive than diesel fuel most of the time, but nonetheless prices for both fuels tended to go up and down together. Starting in 2008 natural gas and diesel fuel prices were uncoupled. Since 2008 natural gas has generally been less expensive than diesel fuel, but more importantly diesel prices have been more volatile and natural gas prices have not responded to the same price pressures as diesel. Diesel fuel prices have and continue to respond to global macro-economic and political forces that affect global supply and demand for crude oil, while natural gas prices have and continue to respond to local supply and demand, driven by the continuing glut of U.S. natural gas production from the shale gas revolution in the US. This means that there is much greater uncertainty as to the future relationship between natural gas and diesel prices than there has been in the past, which significantly increases the risk of a decision by a vehicle owner to invest in the purchase of a natural gas vehicle.	Beyond project scope. **No change**
5.2 In Sec 5.7.1 the authors note that current natural gas engines have significantly lower thermal efficiency than current diesel engines, which is certainly true. However, in Section 4.1 of the report the authors make the case that the future engine changes modeled for this project could significantly narrow the current gap between diesel and gasoline engines in terms of net efficiency, making gasoline engines more cost-effective than diesel engines, especially for medium-duty vocational trucks. The authors should specifically comment and discuss whether the specific engine technologies modeled here for gasoline engines would also be applicable to future natural gas engines (why or why not) and therefore whether the current thermal efficiency gap between diesel and natural gas engines could be similarly narrowed.	**New text added at the end of Section 5.7.1**

Comment	Response
5.2 In section 5.7.2 the report says that "Both fast-fill CNG and LNG vehicles take longer to fill than conventional diesel or gasoline vehicles". Some transit bus fleets (for example MTA New York City Transit) have been able to achieve comparable fill times for diesel and CNG buses using very large fast-fill CNG fuel stations. For a 40-gallon fill (typical of NYC buses) the fill time for diesel and CNG buses varies by less than a minute. To achieve this level of performance a very large and costly fuel station is required, but it is possible.	The general statement is accurate for most of the market. **The word "generally" has been added to the line about fill times**
5.2 In section 5.7.3 when discussing the weight penalty associated with natural gas vehicles the authors state "This weight penalty for natural gas vehicles has a modest negative effect on fuel consumption. Based on the results of the modeling conducted here (weight sweeps) the authors should be able to quantify the range of this fuel economy penalty for different types of natural gas trucks.	**Text added and revised in Section 5.7.3**
5.2 The natural gas vehicle survey does not include any discussion of greenhouse gas (GHG) emissions benefits or dis-benefits of natural gas trucks relative to diesel and gasoline trucks. Given that this report is in support of joint NHTSA/EPA rules to implement combined fuel economy and GHG regulations I believe that the report should include such a discussion. The discussion/analysis should account for net GHG benefits/dis-benefits based on both fuel carbon content and real-world differences in net thermal efficiency for natural gas versus diesel and gasoline trucks. The analysis/discussion should also include upstream emissions of CO2, CH4, and N2O from fuel production and transport, to provide a full wells-to-wheels comparison of natural gas trucks relative to diesel and gasoline trucks.	Beyond project scope. **No change**
6.1 Yes, this section did effectively summarize the conclusions of the report with respect to long haul trucks.	**No change required**
6.2 The discussion of gasoline versus diesel engine results in sections 6.2 should include a direct discussion of the difference between the modeled gasoline and diesel engines on an energy equivalent basis. Perhaps the easiest way to do this would be to include another table, in addition to tables 6.1, which shows "CO_2 Emissions Penalty on Drive Cycle at 50% Payload", in addition to the existing data on "Fuel Consumption (gallons) Penalty on Drive Cycles at 50% Payload"	Since conversion from fuel consumption to CO2 is simple, we decided not to change the tables. This retains commonality between Reports 1 and 2. **No change**

Comment	Response
6.3 In section 6.4, table 6.3 it is not completely clear whether the stated reductions from "engine" and "vehicle" are additive or not. To make this clear the table should include, for each vehicle type, a Total line identifying the range of total fuel reductions possible from both engine and vehicle technologies together. If, for any of the vehicles, the engine and vehicle reductions are not fully additive this should be briefly noted – particularly since one of the purposes of this project was to explore the "additive nature and synergistic relationships between different options for fuel economy improvement". It would also be helpful if this table included the range of percentage reduction in CO_2 emissions available from improved engines for each vehicle type, particularly for those vehicles for which both gasoline and diesel engines were modeled.	**Table 6.3 revised**
7.1 Yes, the appendixes provide sufficient technical detail	**No change required**
8.1 In general this report is well organized, readable, and clear. However the reader's ability to interpret the results and their implications would be enhanced by the following changes: • Reorder the data in all tables and figures in Section 2, so the results are consistently shown with the different drive cycles in order of low to high engine load from left to right • For all tables and figures in Section 2 add one more column which includes results for a weighted average of the CARB, 55 MPH, and 65 MPH cycles, as currently used in GEM for certification under NHTSA/EPA Phase 1. • In sections 2.3.5.16, 2.3.7.1, and 2.3.9.17 add tables, and explanatory text, which directly compare the modeled gasoline and diesel engine options on an energy-equivalent basis (i.e. % reduction in btu/mi or in btu/cycle; or % reduction in gasoline-gallon equivalents (GGE) per mile or GGE/cycle; or % reduction in carbon dioxide (CO2) emissions per mile or per cycle.) • Provide examples of the types of changes that would be required to existing truck models to achieve the different levels of C_d and C_r reduction included in the parameter sweeps.	See discussion above. We decided not to reorder the tables. **No change** Beyond project scope. **No change** The regulations specify standards in gallons per mile or per ton-mile. **No change** **Paragraph added on Section 2.3.3**
8.2 Yes, information provided in the report and appendices is sufficiently detailed to thoroughly document all essential elements of the study.	**No change required**
8.3 The strongest part of the report is Section 2.	**No change required**

Comment	Response
8.3 The weakest part of the report is the Executive Summary - it is too long and complicated. I believe that the report would benefit from a shorter and simpler Executive Summary, more along the lines of the discussion is Section 6, to include: 1) a short back ground on the goals and methodology of the study, 2) a simplified discussion of the types of engine and technology packages simulated (without the very detailed description of each individual engine and technology package), and 3) a high level discussion of the over-all conclusions of the study (without a detailed description of modeling results for each engine and technology package).	**The Executive Summary has been replaced, using material from the original Section 6**
9.1 This report is acceptable with minor revisions. The required revisions are noted above, in particular: 1) re-order data in tables and charts to show drive cycles from low to high engine load from left to right, 2) compare gasoline and diesel engine options directly on an energy-equivalent and/or GHG basis in addition to comparing them on a volumetric fuel basis, 3) use consistent numbering in the description of the engine and vehicle technology packages in tables 2.2, 2.3, 2.4, and 2.5, and 3) shorten and simplify the Executive Summary. These required minor revisions are necessary to enhance the ability of readers to understand the interconnections and implications of the study results.	**All suggestions here are addressed above**

Final Report #2
John Nuszkowski Reviewer Comments and Responses

Comment	Response
1.1 The introduction provides sufficient background on the overall program.	**No change required**
1.2 The hybrid technologies, from Section 2, were not introduced. All other sections were introduced adequately.	**Hybrid systems added to the Introduction**
2.1 The quality, scope, and rigor were definitely there. The models were extensively calibrated with experimental data when available. Many combinations of engine and vehicle technologies were evaluated. The technologies chosen seem to be primarily additive and synergistic.	**No change required**
2.1 What technologies were not additive? I believe this was explored by the author, but not included or discussed in the document.	**Several subsections added: 2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18**
2.1 The model was sufficiently described and is robust. The results will be best case scenarios since the methodology does not take into account transient effects, road grade, and different ambient conditions. These specific conditions are very important, but seem to be outside the scope of this project.	**No change required**
2.2 The technologies selected were logical combinations and pairings.	**No change required**
2.3 The vehicles and drive cycles used were appropriate to get a wide breadth of fuel consumption performance. The vocational worksite trucks drive cycles are still the hardest to quantify. The difficulty of quantifying overall fuel consumption reductions for this vehicle type was addressed through discussion.	**No change required**
2.4 The computer models chosen were appropriate for the analysis. GT-Power is an industry accepted and widely utilized software. The background and validation of the in-house vehicle modeling tool developed by Southwest Research Institute (SwRI) was included in Report #1.	**No change required**
2.5 There were many assumptions applied during the study and they seem reasonable.	**No change required**
2.6 The findings and conclusions are supported.	**No change required**
2.6 The hybrid system results were not discussed and the table wasn't referenced. The text in the hybrid section did not flow with the rest of the document. The table was organized differently and had different significant figures than the rest of the document. This section needs to be cleaned up.	**Two paragraphs added at the end of the hybrid section, 2.3.11**

Comment	Response
3.1 The parameters of drag coefficient, rolling resistance, vehicle empty weight, and axle ratio were realistic. Why was this only done for the medium-duty vehicle segment? The results from the KW T700 were not shown, but the parameters were included in the appendix.	The parameter sweeps were for vocational trucks only. Others were out of scope, so **no change**
3.2 The [parameter sweep] ranges were appropriate.	**No change required**
3.3 The vehicles and engines used were appropriate.	**No change required**
3.4 The results are plausible.	**No change required**
4.1 The section on the potential market shift for gasoline versus diesel engines was very interesting and thorough.	**No change required**
4.2 Within my area of expertise, which does not include market costs, the discussions are accurate and appropriate.	**No change required**
5.1 Within my area of expertise, which does not include market costs, the discussions are accurate and appropriate.	**No change required**
5.2 Within my area of expertise, which does not include market costs, the details are accurate and comprehensive, and sufficiently explained.	**No change required**
6.1 The natural gas and hybrid technology results are not discussed in the conclusions.	**Sections 6.5 and 6.8 added to cover hybrid and natural gas results**
6.2 This section presented the overall conclusions.	**No change required**
6.3 The executive summary and the conclusions section did not reemphasize the limitations and/or accuracy of the model and the reported percent fuel reductions.	**Caveats added in the ES and in Section 6.0**
7.1 The appendices show sufficient technical details. Enough details are shown that similar fuel consumptions results could be reproduced.	**No change required**
8.1 Overall, the report was organized, readable, and clear with only minor corrections needed. See other sections for the changes needed.	**No change required**
8.2 The hybrid technology section needs a more complete and thorough discussion.	**New text added in Sections 2 and 6**
8.3 The wide breadth of combined vehicle and engine technologies analyzed on many different drive cycles was the strongest part of the report.	**No change required**
8.3 The weakest part of the report was technologies that were not synergistic or not additive were not discussed. In addition, the hybrid technology section was weak. The discussion was incomplete and did not flow with the rest of the report.	**Several subsections added on synergy: 2.2.3.2.13, 2.3.3.6, 2.3.5.7, 2.3.5.12, and 2.3.5.18. Hybrid discussion expanded**

Comment	Response
8.4 Throughout the document: - replace the term “RPM” with “engine speed” - Combine one sentence paragraphs with other paragraphs - Replace “&” with “and” - Change “max” to “maximum” and ‘min” to “minimum” - Replace just “speed” with the more specific “vehicle speed” - Figure title spacing is inconsistent.	**Dozens of edits made**
8.4 In the executive summary: Please clean up the short paragraphs and lists without bullet points. “1% combustion efficiency improvement” should be “1% thermal efficiency improvement.”	**Several short paragraphs combined, bullet lists added** **Text corrected in several locations**
8.4 [In the] Introduction: Page 7. Table 2.8 and 2.9 references to “P2” and “P3” was this supposed to be “P12” and “P13”? Please check all the package references. Page 9, first paragraph “pluses” should be “pulses”	**Package references fixed** **Text changed**

Comment	Response
8.4 Section 2: In the tables of engine technology combinations, the term "1% efficiency improvement" is misleading. Please change to "1% thermal efficiency" improvement. Page 28. F-650 is mentioned as having "vehicle packages 2 through 5." From Table 2.8, the F-650 does not have vehicle packages in this number range. Page 29. Table 2.14 also shows these incorrect package references. Page 33. "sees a 3% to 4% with the automatic" should be "sees a 3% to 4% benefit with the automatic". Page 44. Table 2.20 has two "2019 ISB" rows. Page 46. The last paragraph should not be centered. Page 48. Section 2.3.9.10 has a reference to "Package 1" which is incorrect. Page 51. "Ram vehicle packages 2 through 5." The Ram does not have vehicle packages in the range of 2 through 5. Page 55. Figure title at the top of the page.	 **Suggested edits made** **Package numbers corrected** **Package numbers corrected** **Text corrected** This is correct. **Added text above Table 2.20 to explain** **Format corrected** **Package references corrected** **Package references corrected** **Format corrected**
8.4 Section 4: Define "VMT" in the abbreviations section.	**Definition added**
8.4 Appendices: Page 122. Inconsistent spacing. Page 144. Make a complete paragraph for the figure lists.	 **Spacing fixed** Could not find. **No change**
9.1 Acceptable with minor revisions. Please see other sections for my revisions.	**No additional changes required**

BIBLIOGRAPHY

[1] Eastern Research Group, Inc. (2015, February). *Peer review of "commercial medium- and heavy-duty (MD/HD) truck fuel efficiency technology study – Report #1."* (Report No. DOT HS 812 146). Washington, DC: National Highway Traffic Safety Administration.
Available at www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/812146-SwRI%20MDHD%20Tech%20Report%201_Peer%20Review%20Report.pdf

[2] Eastern Research Group, Inc. (2015, June). *Peer review of "commercial medium- and heavy-duty (MD/HD) truck fuel efficiency technology study – report #3*."*[1] Washington, DC: National Highway Traffic Safety Administration.
Available at www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/Draft-SwRI-MDHD-FE-Tech-Report2_Docket-Version_Peer-Review-Report.pdf

[1] Readers should note that this contractor completed a separate cost analysis report for the project that was peer reviewed in the interim period between reviews of Technical Reports #1 and #2. Therefore, the final peer review documentation in Reference [2] above is labeled "Report #3*" instead of "Report #2." This is simply an artifact of the different contract for the peer reviews, which labeled reports sequentially as received and not by name.

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