Peer Review of the Greenhouse Gas Emissions Model (GEM) and EPA's Response to Comments

Phase II

United States
Environmental Protection
Agency

Peer Review of the Greenhouse Gas Emissions Model (GEM) and EPA's Response to Comments

Phase II

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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A. INTRODUCTION

EPA, the National Highway Traffic Safety Administration (NHTSA), and the California Air Resources Board (CARB), in looking to reduce greenhouse gas emissions (GHG) and to improve fuel efficiency in medium- (MD) and heavy-duty (HD) vehicles, are considering recognizing the efficiency of various powertrain technologies within the context of any new full vehicle emission standard(s). For this option, it becomes critical to develop methods that assess the expected real world performance of those technologies, including vehicle engine, transmission and axle technologies.

Enhancements have also been made to their HD vehicle simulation software tool, GEM (Greenhouse Gas Emission Model). At present, GEM is used by vehicle manufacturers to certify the expected GHG emissions of their products. With the enhancements, GEM could potentially have the ability to model a majority of the advanced technologies being incorporated into these vehicles and their engines and that are being recognized by engine and chassis dynamometer emission testing today.

EPA and the other agencies consider the GEM tool as a principal support for the second round of HD GHG emissions regulations which are under development at the present time in both NHTSA and EPA. The model has undergone a formal peer review in an earlier iteration of the GEM tool (Phase I) and this newest version of GEM (Phase II) is the subject of this peer review.

EPA is looking to assure the regulated community of the high quality of the agencies' predictive tool and that the proposed structure (and overall development process) of the GEM model results in a tool that is simple, accurate and well-suited for the diversity of vehicles to which it may be applied. The purpose of the requested peer review is for EPA to receive written comments from experts on the concepts and methodologies upon which GEM relies and whether or not the model can be expected to execute these algorithms correctly.

The purpose of the requested letter review is for EPA to receive written comments from individual experts on GEM Phase II tool and supporting documentation ("Vehicle Simulation Model").

Versar selected four senior scientists with expertise/experience in the following areas to serve as peer reviewers. The reviewers are familiar with the use of models to characterize vehicle simulations/operations; specifically, model design and model code and logic. Additionally, reviewers have expertise in one or more of the following areas:

- vehicle operations and analysis, including the physical process of generating and controlling vehicle emissions;
- linkages between mobile source emission modeling and transportation modeling and planning; and
- application of current mobile source emissions models, w.r.t., heavy-duty vehicles, for analysis for regulatory purposes and/or policy evaluation, e.g., HD GHG Notice of Proposed Rulemaking.

Peer Reviewers:

Christopher M. Atkinson, Sc.D.
Atkinson, LLC
Morgantown, WV 26508

Nigel N. Clark, Ph.D.
West Virginia University
Morgantown, WV 26506-6203

Oscar F. Delgado-Neira, Ph.D.
The International Council on Clean Transportation
Washington, DC, 20005

Ashok Nedungadi, Ph.D., PE
Future Is Now Consulting
San Antonio, TX 78256

B. CHARGE TO REVIEWERS

EPA developed a forward-looking MATLAB/Simulink-based tool, the Greenhouse Gas Emissions Model or GEM, for Class 2b through Class 8 vehicle compliance in 2011. At present, this model is being used by all medium- and heavy-duty vehicle manufacturers for their vehicle certifications. In order to meet EPA's upcoming Phase 2 GHG rulemaking requirements, recognizing most of the vehicle technologies that are measured by both engine and chassis dynamometer testing, the original GEM tool (version1) has been considerably enhanced.

Specifically, the following key technical features have been implemented into GEM:

- Engine controller, including engine fuel cut-off algorithm during braking and deceleration, and more stable engine idle speed controller;
- Transmission model, which includes upgraded manual transmission, newly developed automatic transmission and automated manual transmission; and
- Upgraded driver model, with distance-based driver.

EPA has comprehensively validated its GEM model against over 130 vehicle variants, where all tests, including vehicle chassis and powertrain dynamometers, are conducted at Southwest Research Institute in San Antonio, TX. The summarized comparisons can be seen in the figure below. As can be seen, good agreements between simulation and testing data were obtained, with a few exceptions. For those outliers, it was found that the chassis roller may not be using friction force to correctly represent the truck running on the road, thus causing the chassis dynamometer testing to underestimate fuel consumption.

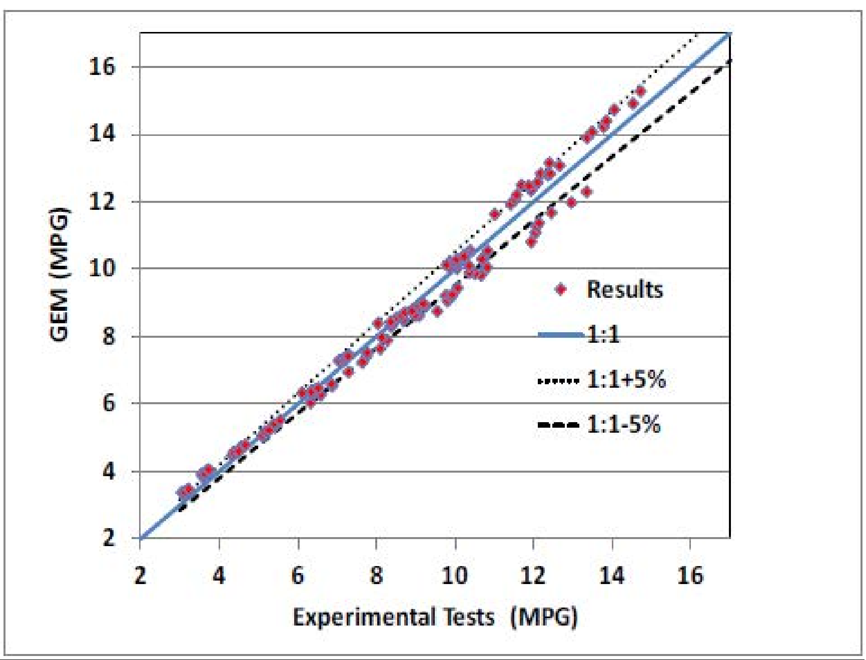

Figure 1. Comparisons between simulations and tests over 130 vehicles under tests

It should be pointed out that CO2 reduction stringency standards in all certification categories are derived from GEM simulation runs by first selecting a range set of vehicle parameters and engine fuel maps. All to-be-certified vehicles from vehicle manufacturers use their own vehicle parameters together with some of the agencies pre-defined parameters to run GEM, and then their results are compared to what the agencies proposed. Since the comparisons are done in a relative base to see if the vehicles can meet standards, it is hoped that this kind of accuracy shown below would be adequate for use of certification purpose.

Please note that GEM includes a pull-down menu mechanism by which it is able to account for those technologies that GEM is unable to model at the present time in development (due to either time constraints or lack of experimental data needed to validate the model). Unlike a model/tool used for research and development simulations where the model can be continuously upgraded and developed, GEM as a compliance tool is constrained by legislative authorities which makes both upgrading the tool and delivering the updated version to users difficult.

Charge Questions

EPA's vehicle simulation model, GEM, was created to serve as the primary tool to certify Class 7/8 combination tractors and trailers and Classes 2b – 8 vocational vehicles in meeting EPA's and NHTSA's proposed vehicle GHG emission levels and fuel efficiency requirements. As both agencies' proposed compliance tool, GEM needed the following modeling attributes:

1) Models a wide array of MD and HD vehicles over various drive cycles;
2) Built with open source code (provides transparency in the model's operation);
3) Available free to any user with minimal, or no, prior modeling experience;
4) Provides both optional and preset elements at input; and
5) Managed by both EPA and NHTSA for compliance purposes.

In general, the purpose of this peer review is for EPA to receive written comments on the concepts and methodologies upon which the model relies and whether or not the model can be expected to execute these algorithms correctly. In making comments on the model, please distinguish between recommendations for clearly defined improvements that can be readily made based on data or literature reasonably available and improvements that are more exploratory or dependent on information not readily available. Any comment(s) should be sufficiently clear and detailed to allow a thorough understanding by the Agencies or other parties familiar with the model.

1. Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?

2. Please comment on the appropriateness and completeness of the contents of the overall model structure and its individual systems and their component models (i.e., using the MATLAB/Simulink version), if applicable, and considering the following:

a) Elements in each system used to describe different vehicle categories;
b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;
c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO_2 over the given driving cycles; and
d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.

3. When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?

4. Please comment on the clarity, completeness and accuracy of the intended output/results (CO_2 emissions or fuel efficiency output file).

5. In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?

C. SUMMARY OF PEER REVIEWER COMMENTS BY QUESTION

Summary of Peer Review Comments on EPA's Heavy-Duty Greenhouse Gas Emission Model (GEM): Phase II and Supporting Documentation

GENERAL IMPRESSIONS

Overall, the reviewers found EPA's Heavy-Duty Greenhouse Gas Emission Model (GEM): Phase II and supporting documentation to be well structured, articulate, and a valuable resource for the EPA to represent the relative efficiency and emissions of heavy-duty vehicles. Reviewers commented that the tool will be very useful for compliance purposes since it is a reasonable compromise between accounting for all technology differences and advances, while remaining simple to execute. A number of improvements in the model and supporting documentation were suggested by the reviewers.

One reviewer commented that the overall dynamic performance of the model prediction is difficult to judge because the results present a single-valued, integrated snap-shot of the model prediction, and the time-based instantaneous fuel efficiency and carbon dioxide emissions predictions are not available for review.

Another reviewer commented that the material does not address quantitatively the experimental error that is likely in these types of comparisons, and measurement errors associated with rolling resistance and drag are not included in the data comparison. Overall agreement with experimental data (as vehicle fuel economy) does not validate each component model to the same degree, and this should be acknowledged more clearly.

Additional suggestions were on the supporting documentation. One reviewer noted that there is an overall lack of key detail on certain technical features, such as descriptions of features, how they were developed, and quantitative results in several areas.

CHARGE QUESTION 1

Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?

In general, the reviewers found that the EPA's overall approach to meet the agency's compliance requirements is valid using the GEM Phase II model. The reviewers commented that a successful approach must yield well-defined, unambiguous results for manufacturers and agencies and also incorporate real world driving dynamics. All of the reviewers acknowledged that the input functions of the model were substantially more beneficial than the original GEM Phase I model. For example, adding fuel maps to the simulation by adding actual maps and drivetrain parameters makes the results more realistic, allows the model to capture the effects of matching engine and driveline, and ideally promotes right sizing of the engines to application.

One limitation a reviewer noted was that the model is oriented toward diesel engines. Naturally aspirated gasoline, boosted gasoline, and natural gas engines are likely to increase in the next five years and may warrant separate and careful consideration because their characteristics, torque curves, and efficiency maps differ substantially from the diesel engine properties.

A few reviewers noted some limitations to the model that were unaddressed by GEM Phase II model. For instance, it is possible for the vehicle not to meet the driving cycle as a result of excessive grade or weight or other issues with the transmission/engine – the unaddressed issue in this regard is a feedback alert to the user during the time instances when the vehicle is significantly slowed down or does not meet the desired driving cycle. Another limitation is that GEM Phase II model does not address thermal characteristics of the engine cooling system or the heat rejection of the transmission fluids – these thermal issues affect the operational duty-cycle of the engine fan, which will affect fuel economy.

One reviewer noted that in order for the public to have confidence in the regulatory program that is built on a mix of engine- and vehicle-model-specific inputs and modeled GEM outputs, the underlying data should be presented in full in downloadable data files (e.g., in Excel) as in other EPA regulations.

Additional issues and limitations are addressed in the reviewers' individual responses to the question.

CHARGE QUESTION 2

Please comment on the appropriateness and completeness of the contents of the overall model structure and its individual systems and their component models (i.e., using the MATLAB/Simulink version), if applicable, and considering the following:

a) Elements in each system used to describe different vehicle categories;

Overall, the model structure and its systems are appropriate and mostly complete for the designated purpose of the model. The specific selection of engines and transmissions chosen will cover a large portion of the current heavy-duty vehicle fleet. The modular structure and the hierarchical arrangement of modules to mimic a real vehicle system makes the integration of additional modules and capabilities easier to implement. One reviewer commented that GEM Phase II cannot predict the benefits of learning algorithms, look-ahead strategies, and intelligent vehicle systems for the optimization of powertrain efficiency on specific routes, but acknowledged that emerging approaches would take great effort to configure.

One reviewer provided detailed comments on specific issues regarding model structure, individual systems, and default values, including: fixed payloads, drop-down technologies driver subsystem, transmission subsystem, engine fueling maps, modeling of idle cycle, trailers, and accessories.

b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;

The reviewers generally found the underlying equations and/or physical principles to be sufficient to characterize real world driving situations. For example, one reviewer commented that the distance-based approach was an important step to represent real life, but also commented that accelerations and grade of cycles must also represent real life. Other suggestions for improvements were also made. A couple reviewers commented on the steady-state maps and on the transient adjustment factor (TAF). For example, one reviewer noted that the use of an engine model steady-state map with a generic TAF does not encourage manufacturers to improve transient fuel efficiency, and provided two possible solutions. Another reviewer commented that in the case of nominally steady operation, the use of a steady-state fueling map is well-justified, but the quasi-steady assumption required to allow the extension of the use of such a map to transient operation requires additional justification. The reviewer also noted that the use of a single TAF for a specific engine or powertrain configuration has the potential to cause prediction inconsistencies. Comments were also made for other components, such as axle efficiency. One reviewer noted that it can be dangerous to employ the overall fuel economy computation to compare two approaches to modeling a single component, particularly if that component represents a small loss.

c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO2 over the given driving cycles;

One reviewer commented that the format for the input and output structures follows good coding standards, making the input/output structures easy to use. One concern is whether there are any other parameters or fitting techniques used to obtain the observed correlations that were not listed in the documentation. Another reviewer commented, as guidance, that the manufacturers will be obliged to use the executable version of GEM Phase II a large number of times to compute an average value for compliance.

d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.

Generally, the default data of GEM Phase II is complete and appropriate to execute a simulation of heavy-duty vehicle powertrain over one of the drive cycles available in the default drive cycle library. However, one reviewer thought it was not clear under what circumstances the user will be able or allowed to make modifications in the final model implementation. For instance, it is not clear that engine cooling fan loads have been adequately accounted for in the model as these are typically not considered in the engine dynamometer testing from which engine fueling maps are normally derived, and they can modify observed fueling rates by about 10% or more under specific engine operating conditions.

CHARGE QUESTION 3

When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?

The reviewers generally agreed that the chosen methods and execution of the model shows strong engineering judgment throughout. Two reviewers commented that it is difficult to comment on the execution optimization of GEM-II. However, one of these reviewers stated that the results, computational time, and outputs displayed indicate that the chosen methodologies are suitable. The other reviewer stated that it appears that there are no S-functions within Simulink, which would make the execution faster if there are any non-standard user defined functions. Another reviewer commented that modeling accuracy would be raised if certain missing components were considered, such as longitudinal slip of tires, rolling resistance during crosswind correction, and the effects of yaw on drag.

CHARGE QUESTION 4

Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).

Some of the reviewers provided suggestions for making the data reports more complete. Some of these suggestions included adding (or clearly identifying) results for each drive cycle, adding actual simulated speeds and a measure of deviation from the speed-distance, and summarizing the results of the energy audit. One reviewer commented that users might be tempted to scale the load-based results in an inappropriate fashion. Another reviewer commented that the results are sufficiently comprehensive for the user who is not executing the program in MATLAB for research and design purposes, and that for a manufacturer a very succinct output would be sufficient.

CHARGE QUESTION 5

In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?

The reviewers provided a number of recommendations for improving the quality of the tool or functioning of the model output. One reviewer suggested that GEM provide two different output reports, including one in an aggregated format with information only relevant for compliance purposes and one in a disaggregated format by cycle with other detailed information. In addition, the output fields should provide a range of valid and acceptable values for parameters such as number of shifts, ratio of number of shifts to number of gears in the transmission, distance traveled, and ratio of actual time to target time. Another suggestion was to make consistent the number of significant digits during each simulation, as the current presentation has a varying number of significant digits which does not meet recommended practices in the presentation of results and data. One reviewer also recommended adding language to remind users that if GEM is used to compare two competing but very different technology packages, it may not have the fidelity or granularity to evaluate which is better. Another recommendation was to provide a quantitative discussion of choice of test weight for GEM. A further step suggested by one reviewer would be to allow users to input their own cycles as is currently done with the VECTO (Vehicle Energy Consumption calculation Tool) model in Europe. A number of other potential model enhancements were recommended by another reviewer, such as including the ability to create input data from a user provided spreadsheet, allowing users to select plots of key component performance, having more detailed explanations of user provided data, providing feedback during execution (i.e. percent complete), having pre-defined sample input data available, including the ability to turn on the feed forward term for the driver model, and having the ability to model accessory power draw in certain cases.

D. PEER REVIEWER COMMENTS BY CHARGE QUESTION

Table 1. General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	The purpose of GEM in determining standards, providing a compliance tool, and estimating real-world benefits is clearly articulated. The proposed Phase II GEM tool has evolved substantially from the Phase I version, particularly by allowing additional user inputs that are necessary to acknowledge fuel efficiency design improvements. As a compliance tool GEM should seek to account for all technology advances and differences, yet remain simple to execute and employ readily-measured and well-defined input variables. The Phase II GEM model has reached a reasonable compromise between these conflicting goals, and this is made clear in the narrative. The overall architecture is sound, the present component models are appropriate to the task in nearly all cases, and they are clearly described. The model yields credible results and credible responses to input variable changes. The overall model predicts fuel efficiency to within 5% of experimental measurements, and a clear summary of these comparisons is presented. However, the material does not address quantitatively the experimental error that is likely in these comparisons, and measurement errors associated with rolling resistance and drag are not included in the data comparison. Overall agreement with experimental data (as vehicle fuel economy) does not validate each component model to the same degree, and this should be acknowledged more clearly. As one example, overall fuel economy data are used to compare a component model with a fixed efficiency value. The difference overall was only 1.67%, but this represented more than a third of the losses for that component. The move to a distance-based strategy is justified and well-described, and represents a laudable advance. Addition of several transmission models is presented, as are thoughts on the addition of transient adjustment factors. Little is said of the "powertrain variant architecture," although this may	Significant progress has been made since we initiated the GEM Peer Review. The technical research workshop held at Southwest Research Institute on December 10-11, 2014 features the progress done so far to the public. In this workshop, both experimental errors and GEM errors were addressed. The detailed progress reports can be seen at http://www.epa.gov/otaq/climate/regs-heavy-duty.htm. The supporting document, "Vehicle Simulation Model", does provide partial validations on the component level, such as the engine and transmission, for selective cases. Due to the large number of vehicle tests and GEM simulations on over 130 vehicle variants, it would be challenging to show every single case validation at a component level. More importantly, the certification is only conducted at the final integrated and weighted fuel efficiency and CO2 level, and therefore, the focus of the model validations is on the overall performance comparisons. The supporting document, "Vehicle Simulation Model", indicates that hybrid vehicles would not be part of the certification with GEM, and therefore, the powertrain described in this report only talks about the conventional powertrain system. We are seeking comment in the NPRM regarding the proposed transient correction

Table 1. General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	prove important for integrated powertrains with or without a hybrid component. Transient Adjustment Factors are not yet finalized, and transient operation may warrant more than a single correction factor approach.	factor of 1.05. We will finalize the transient correction factor after receiving all comments from stakeholders.
Reviewer 2	This document summarizes the findings of the review of the US EPA's Heavy-Duty Greenhouse Gas Emission Model (Phase 2 GEM) and supporting documentation ("Vehicle Simulation Model"). The tool will serve as the principal support for the second round of Heavy-Duty GHG emissions regulations, which are under development by NHTSA and EPA. The agencies are considering recognizing the efficiency of various vehicle, engine, and transmission technologies and they consider critical to develop methods that assess the expected real world performance of those technologies. The main purpose of this review is to evaluate how well the developed model can serve as a regulatory and compliance tool. The following represent my review of the tool and accompanying report based on my experience in modeling heavy-duty vehicles with full-vehicle simulation tools, as well as from our assessment at the International Council on Clean Transportation (ICCT) of other heavy-duty vehicle regulatory models used around the world. After reviewing the Matlab/Simulink model and the accompanying report, my general impression is that the "Phase 2 GEM" constitutes a valuable development effort by EPA to develop a rigorous tool that represents the relative efficiency and emissions of vehicles. The new modeling tools' comprehensiveness, quality and amount of data inputs, and modeling structure reflect state-of-the-art modeling techniques and accurately represent relative efficiency differences of vehicles in real-world conditions.	The literature on vehicle simulation modeling is abundant over the last few decades. Some of the literature used in the supporting documents provides some equations for certain components. The "Vehicle Simulation Model" document was intended to represent a high level overview of the purpose and scope of Phase 2 GEM for regulatory purposes and therefore does not provide detailed technical insight into the model implementation. This document closely resembles the Draft RIA Chapter 4 included with the Notice of Proposed Rulemaking (NPRM) for the HD Phase 2 program. Also the final RIA Chapter 4 will add a few more references to provide more insight into the design and implementation of the model.

Table 1. General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	The model architecture is clear and easy to follow and has incorporated some key features that will enhance its overall accuracy with respect to real world performance of technologies, and will allow the model to capture fuel consumption reductions from a broader range of technologies. Overall, the tool offers a rigorous and comprehensive simulation accounting of both engine-specific and full-vehicle effects in a manner that is suitable for the regulatory compliance purposes as indicated. The model will be capable of performing its intended purpose of reflecting technology benefits for compliance purposes of most of the technologies that the agencies are considering. Some new vehicle modeling features are especially important, namely the ability of the model to incorporate user-defined engine fueling maps and driveline parameters, the development of different transmission options, the enhanced transmission gear-shifting strategy, the inclusion of a distance-based routes with road grade, and the more comprehensive treatment of vocational truck technologies. The accompanying testing effort that was undertaken to validate the model is impressive and thorough, as capturing the effect of combinations of technologies in such close agreement with powertrain and chassis dynamometer testing is a difficult task. The model development demonstrates a thorough development process, and also shows a strong commitment to transparently presenting the data and methodology that were involved. The comments below provide additional details, as well as some suggestions that could also be considered by the agencies in the final model development.	

Table 1. General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	Although the tool itself offers a suitable modeling platform, the document that describes modeling approach could provide further details in a number of areas. It appears as though the documentation available for this peer review was at an early draft stage. There is an overall lack of detail on key technical features that are new in the model. Interested readers would gain from better descriptions of such features, how they were developed, and perhaps, more quantitative results in several areas. Also, the quality of the report may be enhanced with more consistent use of terminology and a reduction in the number of self-references. Further details regarding areas where such documentation and enhanced information would be helpful are described below.	
Reviewer 3	The EPA Heavy-Duty Greenhouse Gas Emission Model (GEM) Phase 2 documentation accurately represents the structure, format, logic and algorithmic description of the model as presented. The supporting documentation is for the most part, clear and self-explanatory. The results produced by the GEM model appear to be sound, although each set of results is presented as integrated fuel efficiency and carbon dioxide emissions results. As such the results present a single-valued, integrated snap-shot of the model prediction, and the time-based instantaneous fuel efficiency and carbon dioxide emissions predictions are not available for review. The overall dynamic performance of the model prediction is thus difficult to judge in the greater context of what is usually fully transient vehicle operation. Furthermore, in the version reviewed, the ability to vary input parameters and vehicle and drivetrain attributes is limited to modifying input files and not through a graphical user interface as described in the review instructions.	We do agree that addition of a graphic user interface (GUI) could help the reviewers to understand the code better. However, the agencies do not intend to develop a GUI for single GEM runs based on discussions with the regulated stakeholders. Instead of a GUI, the NPRM includes a macro-enabled input file based on an Excel spreadsheet (in addition to a standalone executable) with some simple interactive features (highlighting of out of range variables, for example) and a single button to allow batch processing of GEM runs.

Table 1. General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 4	Accuracy of information: The document provided, "Vehicle Simulation Model" provides a good background on GEM-II, its differences from GEM-I, and the Phase I certification process. Section 1.2, "Model Code Description" describes the model components and sub-components, in adequate detail for the user to understand the depth and breadth of GEM-II. No underlying equations are provided. The section on Model validation is an important section for GEM-II. The extent of the validation and the comparisons with dynamometer testing is impressive. This gives the reader additional confidence in the results produced by GEM-II. The validation process is well documented, concluding with the graph that summarizes all the 130 vehicle validations performed. The validation also includes graphs of component performance (engine speed, engine fuel rate, and transmission gear number) as a function of time The document does not explain the variable target.veh_style. The structure format used for the user input data is useful in collecting all user-provided data. A final conclusions section is missing in the document provided.	'target_veh_style' is an internal variable used to track the regulatory subcategory of the simulation run and is not part of the user interface. A final conclusion section could be added into the document, but it is not a critical element, since the documentation was included in the Draft RIA Chapter 4 and is more like a user guide to help the user to understand the structure of the program.

Table 2. Charge Question 1		
Charge Question 1: Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	*Throughout this review, except where different fuels are mentioned, fuel efficiency improvement and GHG reduction are considered to be synonymous.* Beyond the need for assurance of compliance is the need to reduce fuel use and climate change emissions from heavy-duty vehicles in revenue use. A successful EPA approach must be examined from two perspectives. First, it is necessary that the approach yields well-defined, unambiguous results to allow a manufacturer to compare against a standard without the process being unreasonably onerous. Second, it is necessary that that the vehicle attributes and behaviors embodied in the certification process are substantially representative of real world circumstances. These two necessities are often in conflict, because the real world scenario is complex, variable, and long in duration, whereas the standard must be concise and precise. The conflict is far greater in the heavy duty trucking arena than for light-duty vehicles or rail because truck architectures vary widely, and are used in an even wider fashion. Employing a model such as GEM to assure compliance provides some relief in the conflict described above because the model can be executed for a variety of activities and scenarios without excessive cost of time and resources. However, as the model is challenged to predict these varied (and emerging) scenarios with fidelity, the model complexity rises. As a result, the empirical tables or computational sub-models needed within the model grow	The agencies discuss the proposed regulatory approach of separate engine and vehicle standards in the preamble to the HD Phase 2 NPRM and how it may impact the criteria pollutants. We will consider the comments received during the comment period and make any needed changes in the final rule.

Table 2. Charge Question 1		
Charge Question 1: Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	in number and demand substantial engineering time to prepare and verify. One might argue that "the more one models, the more one measures," recognizing too that precise test protocols must accompany each measurement. Compromise is necessary between four fundamental needs: 1. Relevance of the model to real world truck operation. *Else the real world improvements will not match the changes in standards* 2. Accuracy of the model in predicting measured fuel efficiency (and GHG production). *Else confidence in the model will be lost and the compliance will become artificial* 3. Accuracy of the model in predicting differential effects of technology changes on fuel efficiency (and GHG production). *Else the drivers for technology advancement will be lost* 4. Control complexity and cost of modeling and compliance. *Else the cost transferred to the consumers will be inappropriate* The overall new GEM approach shows awareness of these necessities, and reaches a reasonable compromise. However, when some parameters are fixed by the agency, manufacturers may be discouraged from pursuing certain development opportunities in the following way. Both future fuel pricing and future fuel efficiency standards are unknown. If high fuel prices transcend the	

Table 2. Charge Question 1		
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Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	standards, then manufacturers will pursue every cost-effective tool to reduce fuel use. However, if fuel prices are low and are not the driving force, and the GEM approach offers default values for factors such as engine transient adjustment factors or transmission efficiencies, some opportunities for real world reduction may be left on the table. GEM cannot rely on economic drivers to address technology advances that are not modeled. GEM is a vehicle-based tool that is geared towards road-load demands rather than engine-specific ("%load" and "%speed") demands. Only the new distance-based cycles give a nod toward engine power. Criteria pollutants are still characterized using a paradigm based on engine rated output. Allowing different measurement methodologies for efficiency and criteria pollutant production will open a window for separate hardware and software optimization for each test. This may demean the benefits of the separate standards to some degree: in-use compliance for criteria pollutant measurement will not close this gap because measurement allowance for criteria pollutants reduces stringency for criteria pollutants.	
Reviewer 2	The proposed Phase 2 standards are predicated on the performance of a broader range of technological improvements than Phase 1, including changes to transmissions and better integration of engines and transmissions, so a more comprehensive model is required. The model in its current form will be capable of performing its intended purpose of reflecting technology benefits for compliance purposes of most of the technologies that the	In principal, we agree with the comments that the input and output data should be available to public. The agencies will consider in a separate action whether the GEM inputs and outputs submitted by manufacturer to demonstrate compliance with the Phase 2 standards are confidential

Table 2. Charge Question 1		
Charge Question 1: Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	agencies are considering. The model is enhanced in various aspects with respect to its previous Phase 1 version. Fuel maps are one of the most important elements in simulation-based models and the new feature of using actual maps and drivetrain parameters would make the results more realistic, allow the model to capture the effects of matching engine and driveline, and ideally promote right sizing of the engines to application. Different transmission options are included in the model. The shifting behavior is now more realistic since is based on both throttle and speed inputs, and includes the effects of a clutch friction model. Phase 1 GEM shifting strategy was based only on vehicle speed and there was no torque interruption during shifting. Road grade has a major impact on fuel consumption and its addition to the tests cycles would also make the results more realistic. The treatment of vocational technologies, which were limited to the tires in Phase 1, is considerably enhanced. The approach followed by EPA to tackle the diversity of vocational truck applications is appropriate. A few drive cycles are simulated (ARB transient, 55 mph and 65 mph cruise with grade, and a new idle cycle) and weighted differently based on specific application. EPA's approach involved a good amount of testing and validation. It must be said that most of these validation efforts only covered fuel consumption results from reduced weight, better aerodynamics, and better tires. The validation effort for transmission types and engine- transmission-vehicle interaction	business information (CBI). The agencies cannot release information claimed as CBI by manufacturers to the public.

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	was less comprehensive. However, based on the results presented, Phase 2 GEM model would be accurate enough to support regulation and drive technology adoption. More broadly, I make one final comment on how the overall modeling approach may meet EPA's overall goals for the regulation, related to the public release of the GEM input and output data. The existing and Phase 2 heavy-duty vehicle regulation approach relies on the GEM inputs and outputs to determine compliance. The GEM data are analogous to the light-duty vehicle gram/mile[1], heavy-duty vehicle gram/brake-horsepower[2], and light-duty vehicle mile-per- gallon[3] compliance values. For the heavy-duty use of the GEM in the greenhouse gas emission regulatory program to meet the agency's own standard, the input and output data from GEM would ideally be made publicly available just as the regulatory data for the other regulations for each engine and vehicle. For the public to have confidence in the regulatory program that is built on a mix of engine- and vehicle-model-specific inputs and modeled GEM outputs, the underlying data would be presented in full in downloadable data files (e.g., in Excel) as in other EPA regulations. <u>References</u>: [1] EPA http://www.epa.gov/otaq/crttst.htm [2] EPA http://www.epa.gov/otaq/certdata.htm [3] EPA http://www.epa.gov/otaq/tcldata.htm,	

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	http://www.fueleconomy.gov/feg/download.shtml	
Reviewer 3	The model appears to meet the stated purpose for which it was intended, which is the prediction of integrated cycle-based vehicle fuel efficiency and carbon dioxide emissions for vehicles with preselected physical and drivetrain attributes. While this was the subject of some detailed explanation in the model documentation, the assumption of quasi-steady engine fueling and its extension to fully transient engine operation is not without complexity in the assessment of its validity. A further, acknowledged inadequacy of the model in its current form is the limited ability of the user to modify specific vehicle attributes, and component values and efficiencies.	The agencies agree with the comments, and we fully recognize this limitation of the model in terms of the ability of the user to modify some vehicle attributes. As explained in the supporting document "Vehicle Simulation Model" and Draft RIA Chapter 4 the certification is conducted on a relative basis, and the report shows relative errors in the range of 2-3%, which is not perfect, but it is adequate for the purpose of certification. User inputs are limited to reduce complexity and to provide a more common basis for determining regulatory stringencies and to reduce the expense and number of test procedures required to provide accurate inputs to the model. The agencies are seeking comment in the preamble of the HD Phase 2 NPRM regarding the inputs to GEM and the test procedures associated with them.
Reviewer 4	EPA's overall approach to meet the agency's compliance requirements consists of making a validated simulation model (GEM –II) available to OEMs so that they can check the compliance of their vehicles against the agency's guidelines. The extensive validation of GEM – II against dynamometer testing of the actual vehicle shows a good correlation between simulation and	GEM PID controllers are not tunable modules, meaning that the user has no option to change any constants associated with this model. At this time, we have validated GEM against 130 vehicle variants without noticing any issues

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	hardware to within ±5%. Most validations are well within ±3%. This provides the user with a high level of confidence that the physics has been correctly implemented and there are no unresolved "bugs" in GEM-II. Further, an additional level of confidence is achieved, with select validation from four representative vehicle classes, namely: Class 8 Kenworth T700 truck, the Class 6 Ford F650 tow truck, the Class 6 box truck, and the New Flyer Refuse truck. There is a very good correlation between GEM-II predicted engine speeds and transmission gear shifting versus the same on the actual vehicle. Recommendation: It is recommended that representative vehicles from each of the classes be modeled in GEM-II and validation results presented similar to 1.3.1 of the GEM-II Manual. It is the understanding of the reviewer, based on the provided manual that the following trucks were tested on a vehicle chassis: Class 6 Kenworth T270, Class 6 Ford F650, Class 8 Kenworth T700, Class 8 Cascadia Line Haul truck, and Class 8 New Flyer refuse truck. Issues/Results that were not addressed by GEM-II : During this review, the following unaddressed issues were identified for GEM-II: • GEM-II includes several PID controllers within its overall structure. For example, the engine idle speed controller of	associated with PID controller. It should also be noted that many of the PID controllers, like the engine idle speed control, are scaled by non-user-defined parameters like engine inertia or vehicle mass to match their application. The planned interface which manufacturers will use to certify via GEM does not provide the option to output plots. The functionality is not considered necessary to complete the compliance requirements identified in the rule. Thermal modeling is always an issue. Ideally, it should be included in some form. However, it is challenging to develop a correlation to qualitatively predict the thermal impact associated with cooling and transmission heat rejection in terms of a certification tool. This development can be expensive and time consuming. This could place an additional burden on manufacturers who must submit certifiable reports to the agencies, which complicates the process of the certification. Mechanical loads can be also modeled through a simple correlation. However, similar to the thermal modeling issue, this could place an

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	the engine is implemented as a PID with three gains. The unaddressed issue in this regard is stability feedback to the user caused by unrealistic hunting for the idle speed. What safe-guards are in place within GEM to inform the user of clutch chattering since GEM does not model second order inertial effects caused during clutch engagement. • It is possible for the vehicle not to meet the driving cycle as a result of excessive grade or weight or other issues with the transmission/engine. The unaddressed issue in this regard is a feedback alert to the user during the time instances when the vehicle is significantly slowed down and does not meet the desired driving cycle. The output file does not alert the user on the number of time instances when vehicle tracking was compromised. • GEM-II does not address thermal characteristics of the engine cooling system or the heat rejection of the transmission fluids. These thermal issues affect the operational duty-cycle of the engine fan, which will affect the fuel economy. At present, GEM-II models the parasitic loads as a constant average number. Recommendation: Allow the user the ability to introduce an engine load dependent mechanical accessory curve which is more realistic than a constant average number. A simple heat model may be used to capture the effect of thermal characteristics of the multiple radiators in a typical MD and HD engine. • Although GEM-II does not model tire slip/lockup during a	additional burden on manufacturers who must submit certifiable reports to the agencies, which complicates the process of the certification The supporting document, "Vehicle Simulation Model", does show some detailed comparisons in a sub-model level, such as engine and transmission. It is extremely time consuming to show all 130 vehicle variants at such a detailed level. Furthermore, certification only requires composite and weighted values, and therefore, the program should serve this requirement as long as those composite and weighted values are correlated well against the testing data. In terms of transmission shifting, all independent transmission manufacturers we contacted are reluctant to share their shifting strategies with the vehicle manufacturers due to concerns over proprietary information. Therefore, the agencies developed their own generic shifting algorithm for modeling purposes. If GEM under-predicts the benefits of the transmission, manufacturers have the option to conduct powertrain testing where an engine and transmission are evaluated in a

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<tr><th>Reviewer Name</th><th>Reviewer Comment</th><th>EPA Response to Comment</th></tr>
<tr><td></td><td>hard deceleration, the effect of ignoring this on fuel economy is negligible.
The validation results included kinematic comparisons (speeds, gear number) between GEM-II and the actual vehicle on a chassis dynamometer. While, the kinematic comparisons look very favorable, the dynamic comparisons (engine load and engine fueling) are missing in the results section of GEM-II.
The transmission shift strategy can affect fuel economy and emissions. GEM-II allows the user to preselect different transmission types (manual, automatic or automated-manual). However, it was not clear how to modify the GEM-II default shift strategy with an OEM proprietary shift strategy.
Although GEM-II results have been extensively validated against dynamometer test data in a controlled lab environment, it is unclear how well GEM-II will compare against real world road testing, especially with temperature fluctuations. For example, the lack of a thermal model in the engine model may cause GEM-II results to deviate from on-the-road test data, where the engine fan is cycled on and off based on thermal loads on the engine. Each time, the engine fan turns on, fuel economy is affected.</td><td>powertrain dyno cell.

The agencies fully recognize the importance of the GEM validation against real-world vehicle operations. However, it is expensive and time consuming to launch such a program. Currently, the agencies are working with SwRI to conduct this task in the hope that full GEM validation against real-world vehicle operations can be released to public in the second half of 2015.</td></tr>
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a) Elements in each system used to describe different vehicle categories;		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	The proposed GEM Phase II model represents a substantial advance over the model used to implement the first phase of truck efficiency legislation, and encourages more technology advances from manufacturers in consequence. Improvements in truck efficiency are based primarily on reductions in aerodynamic drag, tire rolling resistance and engine brake specific fuel consumption, and this was recognized in the first GEM model. Practically, there is less to be gained from aerodynamic improvements in most vocational truck operation than in long haul trucking and the GEM model as presented neglects vocational truck aerodynamics, and the modelers are right to exclude aerodynamic parameter entries for low speed trucks. However, the overall GEM structure is capable of modeling aerodynamic improvements for niche vocational designs, and has the flexibility to extend beyond the present exclusion of the drag coefficient. In this way, the capabilities of the model, as received, will be far greater than the executable version that is finally used for compliance. A major theme in the industry is that efficiency gains are significant from design integration, particularly powertrain integration. But it is understood that combined powertrain control is proprietary. The supporting language might address this more clearly, noting that the GEM model employs just steady-state maps and a defined set of gear ratios, and cannot predict the benefits of more sophisticated integration. In a	The comments on gasoline and natural gas engines are well taken. The agencies are currently conducting a program at SwRI to address gasoline engine performance related to the rulemaking. We are also actively collecting the engine performance data on both types of engines from manufacturers. The GEM Phase 2 shift algorithm is based on the torque curve and fuel map of the engine and such will adapt shift points uniquely for every engine map provided, regardless of fuel type. Manufacturers will have the option to perform powertrain testing to account for improvements, such as those mentioned by the reviewer. The agencies are seeking comment on whether to include GEM inputs for vocational vehicle aerodynamics in the preamble to the HD Phase 2 NPRM.

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	similar fashion GEM cannot predict the benefits of learning algorithms, look-ahead strategies and intelligent vehicle systems for the optimization of powertrain efficiency on specific routes. These are emerging approaches, but it is acknowledged that it would take great effort to configure GEM to deal with these details and it would be difficult to assure their generic benefit in revenue service. GEM has some check-a-box options proposed for features that cannot be modeled. The model, as provided, was oriented to diesel engines. The shift strategies also considered the engine torque curve for execution. Naturally aspirated gasoline, boosted gasoline and natural gas engines are likely players in the next five years and may warrant separate and careful consideration because their characteristics, torque curves and efficiency maps differ substantially from the diesel engine properties.	
Reviewer 2	Overall the model structure and its systems are appropriate and, in large part, complete. Generally, the performance of each component model and the underlying equations and physical principles are valid throughout (see some finer details below). The input and output structures interact with the model to obtain the expected result in a way that is sound. The following sub-sections comment on specific issues regarding model structure, individual systems, as well as default values, in no particular order of importance. <u>Fixed payloads</u> Phase 1 GEM had predefined engines, driveline parameters, and payloads for every category. An issue that may arise when	Fixed Payload The agencies are fully aware of the technical issues related to payload. However, allowing payload as a variable means that agencies must develop a standard that varies with payload, which would complicate the rulemaking, specifically the process of certification. Furthermore, it would be challenging to verify the in-use payload of a vehicle application, making audit challenging. In addition, this approach would force tractors running without trailer, or bobtail, to be considered

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	using user-defined engine fueling maps in combination with predefined payloads is that some simulated vehicles, with lower power-to-weight ratios, will show higher deviations from the target speed-distance trace. This affects the simulation results since these underpowered vehicles will take more time to complete the assigned route and will show a lower average speed. This could lead to underpowered vehicles being improperly credited. Appropriate matching of engine, transmission gear ratios, axle ratios, and tire radius is only going to be promoted if the GEM payloads closely match actual vehicle operation. Right sizing of powertrains to application does not seem to be promoted when payloads are predefined for a particular vehicle category. In order to recognize engine power matching to vehicle road load, payload needs to be a user input rather than a predefined parameter. The regulatory approach and modeling would ideally recognize and promote market diversity and identify potential discrepancies between actual payloads and GEM payloads. There is an existing trend towards smaller engines, but also some applications require larger engines. On the other hand, if the truck manufacturer is allowed to input vehicle-specific payloads, some issues may arise in terms of enforceability (How do the regulatory agencies ensure that the vehicles are operated close to the payload values at which they were certified?), that may also open the door for the manufacturers to report numbers for their own benefit, and adds complexity.	out of compliance because they are not carrying the declared payload. Therefore, the agencies simplify the process by proposing fixed payload values. Pull-Down Technologies Pull-down technologies are also known as the technology improvement inputs for the rulemaking. The supporting document, "Vehicle Simulation Model" and the HD Phase 2 NPRM preamble describe many aspects of the pull-down technologies. We also seek comment on whether the technology improvement inputs should be in terms of percent reduction or absolute grams of CO_2 per ton-mile. Basically, the agencies have been actively talking to all relevant manufacturers regarding these technologies as selectable items. We proposed a conservative approach recognizing these potential technologies. All the technologies considered as pull-downs would be those that GEM would not be able to model or are not fully recognized over the limited certification drive cycles. Technologies mentioned by this reviewer, such as electric coolant pumps would only show a partial benefit in the engine fuel mapping process, and therefore the pull-down item associated with it accounts for the other remainder of the benefit seen on the road.

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	An option could be to adjust the payload on a few pre-defined bins based on certain parameters that are indicative of vehicle road load (e.g. engine displacement, engine power, final drive ratio). Under this option, a performance criterion that captures the trace-following capabilities of the simulated truck (e.g. a set threshold of percent difference between target speed and simulated speed) can be used to force certain engine-vehicle combinations to switch to a lower payload bin if they don't follow the trace according to the specified criterion. Another option would be to impose a CO2 penalty based on the ratio of simulated average speed to target average speed. Ideally, the allowed deviations from the target trace should be minimized for the simulations to be considered valid and allow comparisons between them. <u>Drop-down technologies</u> The agencies have identified a list of technologies that provide fuel consumption benefits but are difficult to simulate accurately. They are developing feature-based drop-down menus that make post-simulation adjustments (percent reductions) to the results. It appears that manufacturers have not taken much advantage of the Phase 1 advanced technology structure to earn credits so it is important to try to include most of the technologies in some way. However, drop-down menus inherently assume that all the technology variants within a technology category provide the same fuel consumption benefits. Not all the models and brands of a certain technology feature would provide the same fuel consumption benefits. There is the risk of giving artificial credits to products that	Although these values used by GEM are fixed as default values, the user does have the option to use off-cycle credit proposed by the rule, similar to the innovative credits in Phase 1, to quantify the additional benefits of individual technology. Driver Subsystem All the driver model related constants are not tunable. We tested these pre-selected PI controller related constants against over 130 vehicle variants without any noticeable issues. In addition, the driver controller constants are scaled by vehicle mass and therefore adjust automatically for each simulation run. Transmission The auto-shifting tables for all three types of transmissions are different in the form of internal constants which are not user-tunable. The supporting document, "Vehicle Simulation Model", and HD Phase 2 NPRM Draft RIA Chapter 4 includes a table to show the impacts of the shift algorithm on overall vehicle performance as opposed to using manufacturer-supplied shift tables. We agree with the reviewer that we need to provide a clearer description of this subject and it will be clarified in Draft RIA Chapter 4.

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	perform at a lower level than the value that is selected from the drop- down menu, thus rewarding poor performers. Also, technology products with better than average levels of performance would not get additional credits, which is a disincentive to make investments in the development of such technologies. The default improvement values (percent reductions) developed by the agencies were not shared for this peer review but they are of relevance and need to be determined with care. Currently, the users have no flexibility to enter their own values. Giving the users the flexibility to enter their own values (after testing and with proper documentation) could offer a way to reward good performers. It seems that applying adjustment factors in terms of percent reductions rather than applying predefined credits in units of go2/ton-mile or gal/ton-mile may punish good performers. Assuming that truck A emits 90 go2/ton-mile and truck B emits 100 gCO2/ton-mile. If a certain technology improvement value is set at 5%, and both trucks use such technology, truck A would get 4.5 gCO2/ton-mile credit and truck B would get 5 gCO2/ton-mile credit. This discrepancy of incentives can exacerbate if the trucks use more than one drop-down technology and the agencies decide that the percent improvements are additive. So it would be good for the agencies to support whether and why percentage-based (versus gCO2/ton-mile based) are most appropriate. Also the agencies might address, in such drop-down menus whether such technology improvements are indeed additive or not. Another issue with drop-down technologies is that there is the	We fully agree with the reviewer's comments on the powertrain test. As a matter of fact, the powertrain test is one of the options that manufacturers can use to address benefits GEM is unable to fully capture. Engine Fuel maps The proposed engine fuel mapping procedure is detailed in the proposed regulations in 40 CFR part 1036. It is always challenging to use a steady state map approach to account for transient operation. While there are many ways that the vehicle model can be improved for those behaviors, there are always trade-offs in terms of computational speed and accuracy. Furthermore, including more advanced models, such as model based control could substantially improve accuracy, but the collection of test data plus calibration of the model against the data would be beyond the agencies' capabilities, and could be expensive, time consuming and error-prone. This kind of advanced modeling could take much longer to run as opposed to the proposed executable version of GEM, which only takes a few seconds to complete one certification vehicle. It is very typical for a vehicle manufacturer to run thousands of

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	potential for double counting of technology benefits. As an example, an electric coolant pump is listed as a drop-down technology. Depending on the engine mapping process, the resultant engine fuel map may already capture the benefits from that technology. Running a simulation with such a map, and later improving the results using a drop-down menu will double count the benefits. If EPA could respond to how potential double-counting situations are minimal, that would be helpful. <u>Driver subsystem</u> In vehicle simulation modeling, it would seem that the driver ideally would be excluded entirely as a factor that could influence the GEM regulatory compliance results. Using the same driver model for all the vehicles seems to be an appropriate choice. However, additional documentation is needed for this subsystem. There are no details about how the proportional and integral gains of the PI controller have been selected. Are they representative of current drivers? Are they tuned to enhance the trace-following capabilities of the model? The look- ahead feature also lacks documentation. Is it bringing any advantage to the trace-following capabilities of the model? How was the time span value for such feature selected? Ideally EPA would provide some consideration and discussion of such factors to provide greater assurance that no anomalies occur in compliance results from company-to-company technology strategies as well as tested-versus-real-world results for the relative technology benefits. <u>Transmission subsystem</u>	simulations for certification. It is not practical to introduce such complicated modeling processes to perform certification at this time. We propose a single transient factor in the HD Phase 2 NPRM, as the reviewer recommended. We are also seeking comment on the transient correction factor. <u>Modeling of idle cycle</u> The HD Phase 2 NPRM described in Chapter 2 of the Draft RIA and Preamble Section V provides more detailed description on modeling of the idle cycle. Regarding "trace following" and the idle calculation, for tractor-trailers the idle weight is zero and the simulation grams/mile are multiplied by target mph and also divided by target mph so what remains is simulation grams/mile which will reflect the modeled performance (or under-performance) of the vehicle. For vocational vehicles the same is true with regards to the simulation grams/mile over the drive cycles. Idle consumption takes places at zero speed and is measured in grams/hour so there is a

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	There are some transmission-related features that are confusing and need to be clarified. The report mentions that the different transmission models: manual (MT), automated manual (AMT), and torque converter automatic (AT) are built of similar components, but each features a unique control algorithm. However, the model seems to use the same "auto shift algorithm" to determine the operating gear for any transmission type. The differences in the control algorithm of the three different transmissions are not clear and need to be provided. Since transmissions are an important new addition for Phase 2 GEM, it is important to let the reader know that the control strategy (e.g. shift points) or the selection of predefined transmission parameters (e.g. efficiencies and inertias at different gears) are not creating any artificial advantage of one technology type over the others. I suggest presenting a comparison of the same simulated truck with different transmission types. It is also important to highlight in the report that the new transmission controller is based on both speed and throttle position, and differs from the Phase 1 transmission controller, which was solely based on vehicle speed. The rule-based approach of the "auto shift algorithm" would ideally be documented. It would be appropriate for the agencies to acknowledge that Phase 2 GEM simulations can capture some but not all of the benefits of powertrain integration. The simulation would adequately capture engine down speeding since the users have to input specific transmission gear ratios, final drive ratio, and tire radius. However, there are many complexities in the control	conversion factor required to obtain grams/mile. The target weighted average speed represents that conversion factor and does not alter the modeled vehicle performance (or under-performance) over the drive cycles. <u>Trailer</u> The HD Phase 2 NPRM described in Chapter 2 of the Draft RIA and Preamble Section VI provides more detailed description on how trailers are handled. Tractor manufacturers determine the coefficient of drag area for a tractor-trailer combination. The trailer used in this determination is a "reference trailer" that is specified in the regulations (40 CFR part 1037). Details of the test procedures for the tractors are included in the HD Phase 2 NPRM Section III. <u>Accessories</u> The agencies chose the same approach as Phase 1 to model accessories, mainly because it is not an easy task to model accessory improvements, which requires time consuming and expensive testing and validation of the model. Allowing user input of accessory loads would require each user to know ahead of time the expected load for each vehicle in use and while potentially providing more accurate

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	strategy when it comes to integrating engine and transmission. Integrated engine-transmission powertrain approaches with advanced controls and shifting algorithms that many companies are developing could result in significantly more (or less) benefit than the agencies determine as the appropriate default emission-reduction effect. As an example, if two different vehicles have the same driveline parameters (tire radius, final drive ratio, transmission gear ratios, transmission inertias, and transmission efficiencies) and AMT transmissions from different manufacturers, they will obtain the same simulation results in GEM but, due to differing control strategies and other design characteristics, they will show different fuel consumption benefits in reality. It cannot be expected that all the AMT transmissions bring the same fuel consumption benefits. The drop-down menu option won't handle these differences unless there is an option to choose manufacturer-specific transmissions or otherwise input such data. As a result, there is an opportunity here to leverage the powertrain testing and provide the option for manufacturers to better capture the fuel efficiency gains coming from the control strategies and other complexities that are not adequately captured in GEM. Another advantage of powertrain testing is that the manufacturers would not need to disclose confidential information. The results from powertrain testing can then be implemented as correction factors for the GEM results. Using correction factors, GEM results could be multiplied by a fixed	results would place an unreasonable burden on the user and manufacturers. If the accessory is normally part of the engine, the engine mapping conducted on the dynamometer should be able to account for some of those losses, thus being modeled through the engine fuel map. If accessory improvement comes from the vehicle, and GEM is unable to model it, manufacturers can either use pull-down technology or use innovative credit to recognize these accessories.

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	percent improvement obtained by comparing the results of powertrain test and GEM simulations under the same torque-speed trace.[4] The default benefits for transmission improvements would ideally be set to be appropriately conservative (i.e., lowest expected value based on various industry results) in GEM. The drop-down menu could still then be offered as a default, for the manufacturers that decide not to use the powertrain testing. Then, for the powertrain option, companies would ideally be provided clear testing procedures and guidance to demonstrate the emission-reduction impact of their advanced powertrain approaches with physical vehicle testing in simulated real-world conditions. <u>Engine fueling maps</u> The inclusion of manufacturer-specific engine maps is a critical feature to reflect company differences and detailed engine-specific characteristics that reflect real-world fuel consumption and emissions. This is an important addition to GEM, but there is lack of documentation of the engine mapping procedure. I imagine that a fairly prescriptive procedure (including number of points, preconditioning and warming procedures, fuel properties, etc.) is described somewhere else in the larger regulatory development document but this chapter would ideally include a brief description of the procedure so the reader knows which engine accessories are included or excluded during the engine mapping procedure. It is noted that there are many advanced features that may affect fueling but are not captured by using a steady-state fuel	

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	map. Manufacturers are going away from traditional map-based strategies and are going towards model-based controls. Diverse thermal management strategies are utilized, and some engines use dual torque curves. Have the agencies considered how to handle these technologies? This could have important implications for how tested steady-state engine maps, and GEM modeling, and real-world emissions characteristics could differ. As a result, we recommend that the agencies discuss such industry approaches in the rulemaking and investigate ways to ensure that tested results are aligned with real-world engine and vehicle operation the results in fuel consumption and emissions. The approach used to quantify the transient correction factor (run GEM with the engine map, then use the torque-speed points in the engine dynamometer and compare measured versus simulated results) is appropriate. Ideally the transient correction factor may be obtained for each individual engine. However, since there is a need for selection of a vehicle in GEM in order to get the torque-speed trace. It would become a hard task for the agencies to try and run a transient correction factor for each vehicle-engine configuration. For practicality, I recommend provisionally using a single correction factor and maintaining the option to refine it over the years with additional testing. <u>Modeling of idle cycle</u> The idle cycle modeling would gain from increased documentation. Using a gCO2/mile value for an idle cycle at	

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	first seems counterintuitive (i.e., there are no miles traveled) so a complete description of the calculation method would clarify. It would be desirable to present some validation results for the idle cycle modeled in GEM compared to experimental results. Some of the engine auxiliaries may not be enabled while doing the test, and the map could be underestimating actual idle speed fueling rates. There are also engine thermal management strategies that are used to keep appropriate after treatment system temperatures. These strategies vary from manufacturer to manufacturer and could increase idle fueling substantially. The "trace following" issue discussed above also has implications in the calculation of idle cycle g/mile value. For this calculation the fuel rate in units of grams per hour [g/h] is converted to units of grams per mile [g/mile] using the weighted average speed over the three non-idle cycles. The target speed is used for this calculation and not the actual simulated speed, which may penalize smaller engines. I suggest EPA to consider if this issue might be significant. <u>Trailers</u> Although there is a parameter in GEM for trailer tires' rolling resistance, it is not clear how trailer aerodynamics is going to be modeled in GEM. Trailer aerodynamics can bring about two-thirds of tractor-trailer aerodynamic benefits, so this is a critical area that requires documentation and specification of the procedures for the vetting, binning, and including the input data. My understanding is that the Coda input parameter is for the tractor only (mid-roof and low roof tractors are tested in its	

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	bobtail configuration), or for the tractor using a "reference" 53-ft dry van trailer (for high-roof tractors coast-down test). Trailer aerodynamic devices can reduce the overall tractor-trailer combination aerodynamic drag and ideally the Coda used in simulation should represent the combination. It seems that there is no current provision to include the effect of trailer aerodynamics as an input in GEM. The report needs to clarify how the GEM model is handling trailer parameters (including aerodynamics, tires rolling resistance, and weight reduction) and if the model is going to use a predefined "reference" trailer for all the tractors. Ideally agencies would give credit to tractor-trailer integrated designs although it would be difficult for the agencies to ensure in-use compliance of matching of tractors and trailers. <u>Accessories</u> There are opportunities for fuel savings from mechanical accessories and electric accessories but the agencies decided to keep with the Phase 1 approach of having pre-defined and not customizable power from accessories. If these parameters are assigned default values, there are no incentives to implement new technologies that could have greater impact. Allowing accessories power consumption to be user-defined inputs can be used to promote developments in technologies that reduce the power requirements of accessories such as the alternator, air-conditioning compressor, power steering pump, or cooling fan. There are other opportunities for engine accessories such as oil, coolant, and fuel pumps, but is not clear at this point if all those savings are going to be captured by the engine	

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	mapping process. References: [4] See Sharpe, Delgado, Muncrief (2015) Comparative assessment of heavy-duty vehicle regulatory design options for U.S. greenhouse gas and efficiency regulation. http://www.theicct.org/us-phase2-hdv- regulation-design-options	
Reviewer 3	The elements in each of the systems (engine, transmission, axle, vehicle attributes etc.) seem appropriate and complete. The specific selection of the engines and transmissions chosen will cover a large portion of the current heavy-duty vehicle fleet, although of course any specific, single selection of powertrain hardware or powertrain hardware attributes necessarily limits the range of vehicles that can be simulated with that same selection.	Non-conventional or alternative powertrains can be certified through powertrain testing.
Reviewer 4	The three main powertrain components that can affect fuel economy and greenhouse gas emissions in a vehicle are: engine fuel map, transmission type and efficiency map, and vehicle aerodynamic improvements (including tire rolling friction improvements and weight reduction technologies). In this regard, GEM-II addresses all the aforementioned components by providing steady state maps for each powertrain component, which an informed user can change to represent specific technology improvements. GEM-II comes with certain standard transmission models, namely: manual, automatic, and automated manual transmissions. The user would select the appropriate transmission and GEM-II would automatically select the user-specified transmission.	The proposed Phase 2 version of GEM for certification is an executable version code, which does not require Matlab/Simulink license. In additional, a plain text formatted file will be used for user inputs. There is no need for user to understand the coding structure of GEM in a Matlab/Simulink format. Neither manufacturers nor users will be able to modify the structure of GEM in any way. The Phase 2 GEM User Guide, provided with the NPRM, will provide details on how to use GEM. A technology improvement such as a proprietary

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	Recommendation: It is recommended that additional instructions are provided if the user wants to change the engine map. Ideally, this would be done from a user specified spreadsheet in a GEM-II compatible format, since the user may not be fluent in Matlab. In this regard, a clear explanation of all the variables used in GEM-II would also help significantly. For example, it was not clear how to change the transmission shift schedule if an OEM chose to do so. Further, since GEM-II is modular with hierarchical layout of component layers, it is challenging for an OEM user to insert a technology improvement deep within one layer and not affect the layers above or the execution of GEM-II. It is not clear, from this initial review, how a technology improvement such as a proprietary transmission shift schedule can be evaluated in terms of gains in fuel economy and greenhouse gases. This comment applies to other technology improvements as well, such as partial engine cylinder deactivation (power on demand) or electrification of certain mechanical accessories. The vehicle categories that GEM-II addresses range from Class 2B to Class 8 HD conventional vehicle powertrains. This is achieved by four root-level systems in GEM-II at the root level, namely: the ambient, driver, vehicle, and powertrain modules. Each of the aforementioned modules consists of several sub-modules organized in a hierarchical manner. Each root-level module outputs a data bus that is mixed into a single data bus. The aforementioned four main systems of GEM-II correspond to the four main components of a HD vehicle, namely: driver,	transmission shift schedule would not be considered under the current GEM. Rather, the agencies encourage the user to use the powertrain option described in Chapter 3 of the HD Phase 2 NPRM RIA to address any benefits associated with the transmission and its integration with the engine that GEM is unable to model.

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	ambient conditions, vehicle chassis and powertrain modules. This one-to-one correspondence between the root-level GEM-II models and an actual HD vehicle makes for an easily understandable structure. Further, the modular organization of the GEM-II contributes to easier debugging and isolation of a numerical problem during simulation. The powertrain module is the most populated module in GEM-II. It contains the engine, transmission and driveline sub-modules and accessories (mechanical and electrical). The flow of data information corresponds to an actual vehicle powertrain, with the engine output driving the transmission, which in turn drives the driveline components. The modular layout of GEM-II, its correspondence with a real conventional vehicle is therefore appropriate and complete for the reasons stated above. The modular structure and the hierarchical arrangement of modules to mimic a real vehicle system makes the integration of additional modules and capabilities easier to implement. The signals are clearly marked and follow a logical naming convention that facilitates the addition of additional modules and capabilities into GEM-II.	
b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;		
Reviewer 1	MATLAB/Simulink remains an excellent basis for the GEM model. It is well suited for the exploratory and development framework, as well as the production of a more limited executable model.	The agencies use their own auto-shift algorithm for all transmissions for many reasons as described by the supporting document – "Vehicle Simulation Model". We recognize that this is not an ideal modeling approach, but we do offer the powertrain

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	GEM may be viewed on three levels. At the highest level, the MATLAB/Simulink platform allows GEM to be anything it chooses, with the addition or alteration of modules and component models. At the second level, there is the model provided for review, which has the innate ability to deal with a wide range of cycles and truck configurations. At the lowest level will be the final executable version, where certain parameters are fixed, and where the duty cycles are chosen for determination of compliance. Only the second and lowest levels can be considered in this review. This GEM model is being produced at a time where engine control strategy development and integrated powertrain controls are advancing rapidly. Also, transmission options are now far wider than in the earlier GEM model, where unsynchronized manual, synchronized manual and traditional automatic transmissions dominated the marketplace. GEM is challenged in modeling and giving credit for the technology subtleties that will emerge in the marketplace over the next five years. The use of distance, rather than time, as a basis for the test cycles represents a great and important advance. It was widely recognized two decades ago that light duty automobiles were capable of far more aggressive performance than was embodied in the FTP-75, although the FTP-75 was used as the norm, and still embodied allowances for vehicles that could not follow its modest accelerations. In the heavy-duty arena sustained use of full engine power both on grades and during acceleration is the norm. All else being equal, a more powerful truck will	testing approach that allows manufacturers to quantify the benefits associated with their own more advanced shifting technologies and integration benefits with the engine. We are fully aware of the limitations of the steady state engine fuel maps that are proposed for GEM. We proposed the concept of the transient correction factor for the transient cycle to minimize the deficiency of the steady state map. We are also aware that this transient correction factor is derived from the diesel engine test, where gasoline and natural gas engines may behave differently. We are currently asking for comments on this approach. We will make refinements in our final rulemaking, as needed based on the comments we receive. In addition, manufacturers have the option to conduct powertrain testing to demonstrate their engine's transient performance. At this time, we are proposing a single value for axle mechanical efficiency, and ask for comments of whether we should use a look-up table to model axle efficiency based on axle efficiency test results. The agencies will make appropriate adjustments in the final rule based on the comments received. It is not straight forward to model tire rolling resistance as function of speed without

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	complete its duties in less time than an underpowered vehicle, and often the more powerful choice represents the overall economic optimum. However, the more powerful truck will spend less time at full power, and will enjoy a reduced average "%load" in revenue service. The adoption of the distance-based approach is an important step toward matching the GEM model to real-would use. However, as standards are finalized, the accelerations and grades of cycles embodied in the GEM execution must represent real life as well. If the grades and acceleration values are not appropriately challenging, the distance-based approach will look more like a time-based approach, because underpowered trucks will be able to follow the trace in the minimum time allowed. This would divorce the market incentives from the environmental incentives and create a false impression of fuel efficiency capability at the expense of economic reality. It is important that the grades and test weights used are realistic and representative. Further, the indication of the ratio (actual / minimum time for cycle completion) is a very beneficial output value. A driver's habits are known to have a measurable impact on truck fuel efficiency. This is in part due to gear selection that influences the engine operating envelope, and in part due to transient pedal demand (driver PI controller), that may cause an engine to depart from steady-state mode to a greater or lesser degree. The GEM load demand controller and GEM gear selection algorithms can be configured to reflect different driving habits. If the chosen GEM driver yields a better fuel efficiency than would be expected of the national average	comprehensive tire data. Besides, just like the comments made by this reviewer, detailed tire data of this kind are not in the public domain and test methods are not universally defined. It is challenging for the agencies to develop a more advanced tire model at this time. The agencies present details of the proposed road grade cycles in the HD Phase 2 NPRM preamble and welcome comment on the representativeness of these and other road grade profiles developed. The agencies will reflect the final road grade profiles in the final version of the HD Phase 2 GEM.

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	driver, then GEM will fail to grant auto-shifting technology and certain engine control strategies their full potential contribution to efficiency gain. It is recommended that this issue is at least explored to provide driver sensitivity results to the accompanying document. The engine model in the new GEM is still a steady-state map. The documentation acknowledges that transient fuel efficiency will differ from steady-state efficiency at the same speed and load in time. A transient adjustment factor (TAF) seems likely for the final version, but the use of a steady-state map with a TAF does not encourage manufacturers to improve transient fuel efficiency if a generic TAF is assigned. This reviewer appreciates that manufacturers are unwilling to reveal strategies that represent a substantial fraction of product value, yet they cannot take advantage of their improvements in the model without this information. Two solutions are possible: (i) Determine a manufacturer-specific TAF rather than an agency-specified TAF, or (ii) Determine an alternate fuel efficiency map for transient (e.g. Heavy-Duty FTP) operation, and use that map or both steady state and transient maps for the transient cycle. In addition, TAF will need to be considered carefully for gasoline and natural gas engines, where enrichment management has an important effect on fuel efficiency. In a similar way, cylinder deactivation strategies may be difficult to	

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	characterize for throttled engines, because the deactivation strategy is not well represented by a steady-state map. It is important to have a TAF strategy that acknowledges successes of manufacturers in lowering transient operation disadvantages. The EPA developers have sought comment on the issue of axle efficiency. It can be dangerous to employ the overall fuel economy computation to compare two approaches to modeling a single component, particularly if that component represents a small loss. In one case, the overall fuel economy differed by 1.67% when a simplified efficiency was compared with a lookup table for rear axle efficiency. This 1.67% represented more than a third of the loss associated with that component. To place this in further perspective, the 1.67% can be compared to the 3-5% contributions of a major component, such as side skirts on a semi-trailer at freeway speeds. Generically, if a component model with higher fidelity is available, in the opinion of this reviewer, it is worth including the detail in GEM, even if the component model is fixed in GEM. Furthermore, the existence of such a model may provide a clearer pathway for entering technology advances by a manufacturer who improves that component in the future. The tires in GEM are simply characterized by a rolling resistance coefficient and an effective loaded radius. It is known that the coefficient varies with vehicle speed and contact area, while longitudinal slip can change the revolutions per mile by a few percent under driving torque and braking, which could bias results more substantially when grade is	

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	present. This could be coded into GEM, but it is probably more appropriate to treat it as a comment, since detailed tire data of this kind are not in the public domain and test methods are not universally defined.	
Reviewer 2	See response for part A.	
Reviewer 3	One concern with the structure and form of the model is that a steady-state engine fueling map is used in each case to simulate transient engine operation and hence dynamic vehicle operation. This is in addition to the simulation of operation under nominally steady vehicle speeds or cruise operation. In the case of nominally steady operation, the use of a steady-state fueling map is well-justified, but the quasi-steady assumption required to allow the extension of the use of such a map to transient operation requires additional justification. Heavy duty compression ignition engines have high rotational inertias (due to the relatively high mass components required to survive the high combustion pressures), high mechanical friction (due to high effective compression ratios) and relatively slow air and exhaust transfer processes (due to the excess air flow rates accompanying their lean, un-throttled operation). In addition they have relatively high thermal mass due to their large physical mass required to withstand the stresses and strains resulting from high combustion pressures. All of these features conspire to result in deleterious combustion effects under highly transient engine operation. In most cases the end effect of these phenomena is to reduce the engine brake thermal efficiency under transient modes, beyond that which would be expected under steady or quasi-steady fueling operation. In most cases the additional fuel that is required to undertake a	We are fully aware of the limitations of the steady state engine fuel maps that are used for GEM. We introduce the concept of the transient correction factor for the transient cycle to minimize the deficiency of the steady state map. We are also aware that this transient correction factor is derived from the diesel engine test, where gasoline and natural gas engines may behave differently. We are currently asking for comments on this approach. We will make refinements in our final rulemaking.

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	specific engine transient torque trajectory, beyond that estimated using a quasi-steady fueling assumption, would typically be less than 10% of the total integrated fueling, but in most cases the effect on integrated fuel efficiency over transient duty cycles is non-negligible. In general, incorporating an additional component into the full accounting of the vehicle load by over-accounting for the actual total rotational inertia (in the form of an effective or "added" mass or inertia) of the drivetrain and driveline system does allow for the quasi-steady assumption to hold. However in general a quasi-steady, forward-looking simulation such as is used in this model, tends to under-predict the actual vehicle energy usage under transient duty cycle operation. I notice that this issue is addressed in Chapter 1.4.1.8 Transient Adjustment Factor, but the designation of a single correction factor for a specific engine or powertrain configuration is likely to be unsuitable in some cases, and has the potential to cause prediction inconsistencies. Note further that the required correction factor might not be uniquely engine-specific, but might vary for the same engine in different vehicle and powertrain configurations.	
Reviewer 4	GEM-II follows the model of a single wheel with a concentrated mass at the center of the wheel. The physics coded into the modules are based on Newton's second law of motion for this concentrated mass. At the time of this review, no other dynamic equations were found in GEM-II, except in the clutch and torque converter. The engine, accessory, transmission and driveline components are characterized by	The model physics are Newtonian, as noted, and follow textbook equations for Newton's laws and conservation of energy.

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	steady state maps. The equivalent mass of rotating inertia components are also correctly included in the vehicle module of GEM-II. Rotating inertias are correctly reflected downstream to the tire. The inertia is converted to a virtual mass which is added to the entire vehicle mass. The wide validation of GEM-II against real vehicle data indicates that the physics has been correctly implemented in GEM-II.	
c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO2 over the given driving cycles;		
Reviewer 1	The accompanying explanatory document emphasizes that the input and output structure has not been finalized. A comment, intended as guidance, is that manufacturers will be obliged to use the executable version of GEM a large number of times to cover each order or each truck technology change over the year. This is needed to compute an average value for compliance. The EPA should make every effort to insure that the final version can be interfaced with the manufacturers' software to insure that the process is efficient and reasonably inexpensive, while keeping that version of the model locked to insure compliance. The .csv output files, viewed in Excel, provide a representation of likely input and output files. These summaries are very useful and appropriate.	The agencies are talking to various manufacturers to make sure that our input and output structure can be integrated with their software. The HD Phase 2 NPRM preamble seeks comments from stakeholders on suggestions to minimize the compliance burden associated with GEM.
Reviewer 2	See response for part A.	
Reviewer 3	A further concern that is not discussed in the documentation is whether any model fitting parameters were employed to obtain the fits observed, between the GEM-derived fuel efficiency and CO2 emissions values and the dynamometer-measured results.	Some model constants were adjusted to match the individual vehicles, however all simulations for a particular vehicle are run with the same configuration.

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	In other words, beyond the parameters described and the accompanying constants used in the dynamic force and energy equations, were any other fitting techniques (or fitting parameters) used to obtain the observed correlations between the simulated cycle-averaged results and the SwRI chassis dynamometer results? Presumably there were dynamometer parameters and coefficients fitted using vehicle coast-down data (and dynamometer operational parameters), but beyond these, are there any other fitting parameters used to obtain the correlations shown? Discrepancies between simulated and measured results of less than 2-3% are probably not significant, except in the presence of a consistent bias between the measured and predicted, for any one vehicle, cycle or technology considered.	Examples of adjusted model constants are transmission shift delays, rpm limits, up and down shifting constraints, first gear skip, etc. However once these model constants are tuned, they are not adjusted for individual drive cycles or tests. In other words, vehicle-specific constants are set up to match the behavior of the vehicle but are not tuned for individual results. Input values directly from experiment, such as coast down data related to aero drag coefficient and tire rolling resistance coefficients are taken as inputs and not further adjusted.
Reviewer 4	Input for GEM-II: A structure format is used to store the inputs to create the input data for the execution of GEM-II. The structure format is organized as follows: component.variable.units. For example, the input variable "engine.idle_fuel_map_speed_radps" identifies the engine speed vector of the engine idle fuel map expressed in rad per sec. Similarly, the input variable "transmission.clutch.input_inertia_kgm2 refers to the clutch inertia of the transmission, expressed in kgm2. This format follows good coding standards, making the inputs easy to pair to the appropriate component it refers to, the particular variable name, and the units used. Further, a modular approach is used to store the input data for each component in separate easily identified files in the "param_files" folder.	Although this reviewer makes excellent comments on the model data structures based on Matlab/Simulink, the actual code used for certification is only an executable version of the code, meaning that it will not require a Matlab/Simulink license and the user would not touch the source code, and therefore, these comments are not relevant to the certification tool.

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	Output for GEM-II: When the workspace has been populated with the input data, the simulation model "REVS_VM" vehicle model is executed over the user-selected drive cycle. Each major component model (GEM_CVM, vehicle, driver, ambient) has a bus_out output port which contains a structure of component output data, which is used within other components. In addition, GEM-II uses a datalog structure to store simulation output data for later post processing to calculate emissions and fuel economy. All the simulation output is stored in a single datalog structure with multiple fields, each describing the component that the data pertains to. For example, datalog.vehicle.speed_mps refers to data log from the vehicle component of the variable vehicle speed in m/s. This format is an accepted coding standard within other vehicle simulation packages (such as PSAT from ANL, RAPTOR from SwRI) as well, making the output easy to pair to the appropriate component it refers to, the particular variable name, and the units used. Similarly, all variables that are used to perform an energy balance are prefixed by "audit". Interaction with the model to obtain the expected results: The bus_out structure from the various components are stored in "goto" blocks which are paired with "from" blocks to distribute data from one block to another. The use of paired "goto" and "from" blocks is an accepted method of decluttering the simulation model and avoiding crisscrossing signal lines, thereby significantly facilitating the understanding of	

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	information flow from one component to another.	
d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.		
Reviewer 1	The default values are not particularly important at this stage of development. They are sufficiently representative of recent or current technology to provide reasonable inputs and to assess the ability to predict real-world values. However, this is an appropriate point to acknowledge and discuss the comparison of GEM output with real-world measurements, as described in the supporting material. The real-world data serve to verify the ability of GEM to model a variety of trucks. These data do not extend to the validation of truck tire rolling resistance or aerodynamic drag value selections because the validation was conducted using roller and powertrain dynamometers, where these values were entered and were the same values used in GEM. Generally GEM matched the measured fuel efficiency values to within 5%, and the deviation may be attributed both to measurement error and to the inherent simplifications in modeling. There are some systematic errors evident in the comparison. For example, the T700 truck efficiency is underpredicted (GEM vs. measured) on the high speed tests and overpredicted on the low speed tests. This trend differed for the T270 and F650 trucks. The refuse truck fuel efficiency was uniformly overpredicted. This leads to the conclusion that GEM may be capable of predicting overall fuel efficiency accurately (at the 5% difference level), but that one should still be cautious of comparing the performance of very different technologies using the GEM tool.	The agencies agree with this reviewer's comments. It is a daunting task to verify every GEM sub-model, which would require significant investment to collect data and then validate each sub-model. Just as this reviewer pointed out, the single overall predicted efficiency is of interest to the manufacturer because it predicates compliance. GEM works reasonably well to predict this single value, namely, fuel economy over 130 vehicle variants. The agencies have made significant improvements on the driving cycle. The addition of road grade to 55 and 65 mph cruise cycles is just one example. The agencies are seeking comment on the proposed drive cycles and road grades in the HD Phase 2 NPRM. We will refine GEM as necessary based on the comments for the final rulemaking.

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	The narrative states that "While it is encouraging that GEM accurately simulates overall vehicle performance in an absolute sense, it is actually more important that GEM is accurate in relative comparisons." This is true in the sense that GEM should encourage the best technology pathways through comparison, but it is nevertheless the single overall predicted efficiency that is of interest to the manufacturer because it predicates compliance. As an example, when the axle ratios were adjusted for a vocational truck from the chosen value of 3.76 to high (4.06) and low (3.46) values, the predicted transient fuel economy values were 5.55, 5.49 and 5.6 respectively. In contrast to this small variation, the fuel economy values for the 65mph operation were 7.14, 6.88 and 7.37 respectively, attributable to the 9% difference in engine speed between the high and low ratios. This reviewer has confidence in these relative values where a variable input is changed. However, a comparison between two vehicles with identical chassis and bodies, but with different engines, transmission types and tire rolling resistance challenges several parts of GEM in a differential sense, and a greater comparative error must be anticipated. One cannot argue that the overall agreement with the measured data verifies each sub-model within GEM. The use of single variables to represent a more complex reality is discussed elsewhere in this review. The cycles chosen for evaluating vehicle performance can be	

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	changed readily in GEM. Although incorporation of grades represents a substantial advance, the current choice of fixed 55mph and 65mph steady speeds may cause designers to "teach to the test." [The CBD cycle, used in a previous age to quantify transit bus performance, suffered from problems of this kind because all steady state operation was at 20mph.] The output data for the tractor (through engine speed / vehicle speed ratio) show that the highest gear was used for both fixed speeds. Use of a test cycle where speeds varied slowly through the 50 to 70 mph range could avoid pitting real world optima against model optima, and would encourage engine downspeeding strategies that are successful in revenue service where speed limits are not necessarily 55 and 65mph.	
Reviewer 2	See response for part A.	
Reviewer 3	The default values as defined in the "Vehicle Simulation Model" are reasonable and currently fall within the ranges of expected vehicle values. It is not clear however under what circumstances the user will be able or allowed to make modifications in the final model implementation. For instance, it is conceivable that the interplay between future auxiliary mechanical or electrical loads on an engine might be significantly modified through conversion of mechanical auxiliaries to electrical or electronic devices. In that case, that will shift the relative balance in those loads. Moreover it is not clear that engine cooling fan loads have been adequately accounted for in the model, as these are typically not considered in the engine dynamometer testing from which engine fueling maps are normally derived. This exclusion alone can modify observed fueling rates by 10% or more under	The example mentioned by this reviewer of the coolant fan is an example of a technology that GEM cannot directly model at this time due to lack of data and the extra burden of testing that would be required to calibrate such a model. In general, GEM will recognize all technologies that can be measured during dynamometer cell testing through the engine fuel mapping procedure. Those that cannot be measured or cannot be modeled through GEM will be accounted for in different ways through (1) the pull-down technologies item or technical improvement input values (2) Powertrain test options (3) Innovative credit

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	specific engine operating conditions. Other default values including transmission gear ratios, transmission efficiencies, axle efficiencies, tire rolling resistance, and vehicle aerodynamic drag product seem reasonable.	
Reviewer 4	The default data used in GEM-II is complete and appropriate to execute a simulation of HD vehicle powertrain over one of the drive cycles available in the GEM-II default drive cycle library. The default ambient conditions summarized in ambient_param.m are appropriate. The default driver parameters, summarized in driver_param.m, contain driver gains as well as the time that the driver can look ahead in the drive cycle. The driver gains represent an average driver, which the user can change to emulate an aggressive driving pattern versus a calmer driver. The default engine maps of 270 kW, 345 kW, and 455 kW power ratings includes inertia, idle speed. Default transmission maps for the manual, automatic, auto-manual are also available. Default tire radius, axle ratios, rolling resistance of the tires of the steering axles and drive axles are also included.	The certification tool is an executable version, and the user will not be able to access the source code for certification. Therefore, the user will not have flexibility to change model constants, such as driver gain.

Table 4. Charge Question 3		
Charge Question 3: When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**

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Charge Question 3: When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	The GEM tool as presented to the reviewers provided a workable compromise between accuracy and simplicity. It is evident that GEM may be improved in accuracy by increasing input data, in particular the substitution of data tables for single values. However, these tables would need to be created for each component at substantial expense. Also, it would be better to use real values or tables or strategies from manufacturers, but each of these might require audit and prescribed measurement methods, and in many cases the manufacturer considers them to be proprietary. The present GEM is close to being optimized: clearly development is still taking place. As a general observation, the engine and transmission receive substantial attention in GEM and in much work on truck efficiency improvement. They seem to be of interest at the single percentage level. However, tire rolling resistance is a major influence for vocational trucks, and drag coefficient controls the dominant loss for freeway tractors. Yet these two components are each represented by a single parameter. Beyond just GEM, a more detailed consideration of these components (e.g. longitudinal slip of tires, rolling resistance during crosswind correction, effects of yaw on drag) would assist in raising modeling accuracy. If that cannot be considered expediently for this version of GEM, it should be considered in the future, or even embedded in the tables so that it can be applied without altering the code.	We fully agree with this reviewer's comments. The current version of GEM is a balance of model fidelity and simplicity. The agencies could develop more advanced features, but at higher cost of development and longer duration, which would not be able to meet the timeline of this rulemaking. In the future, many advanced technical features including the tire model mentioned here could be considered. The agencies are proposing to account for the effects of yaw on drag in Phase 2 in the CdA input to GEM. The HD Phase 2 NPRM preamble Section III describes the test procedures to determine the wind average yaw coefficient of drag value and we seek comment on the proposed approach.
Reviewer 2	The chosen methods and execution of the model shows strong engineering judgment throughout. A good indication of proper	We appreciate the comments made by this reviewer.

Table 4. Charge Question 3		
Charge Question 3: When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	execution is the overall good agreement between the Phase 2 GEM simulations and testing data obtained with chassis and power train dynamometers. The errors shown are well within +/-5%, which is within the test-to-test variability of chassis dynamometer testing. Execution at this level of fidelity meets our own criteria that we have utilized to validate tractor-trailer simulation results.[5] the validation results show that the balance between model accuracy and simplicity is adequate. As a result, the program would be effective to model a diverse set of technology changes and be used in regulatory applications. References: [5] See Delgado and Lutsey (2015). Advanced tractor-trailer efficiency technology potential in the 2020-2030 timeframe http://www.theicct.org/us-tractor-trailer-efficiency-technology	
Reviewer 3	This issue is difficult to address through the level of observation afforded to the reviewer at this stage of development of the model. It is not obvious that the program execution is optimized, but the results, computational time and outputs displayed indicate that the chosen methodologies are suitable for this purpose.	We appreciate the comments made by this reviewer.
Reviewer 4	Overall, GEM-II uses industry accepted coding practices throughout the software modules. The following is a partial list of these accepted practices: • Valid variable naming structure used – • Data bus used for each component – • Modular components with no signals crossing – • Useful comments to assist the user with following the	The comments made by this review are well taken in terms of improvement of the Matlab/Simulink version of the source code. We should point out that the certification tool is an executable version of GEM, and the user would not be allowed to use the Matlab/Simulink version of the source code to perform certification.

Table 4. Charge Question 3		
Charge Question 3: When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	code – • Energy audit adds to the confidence level of the results of the simulation. • File name that is executed is echoed back to the user. If there is a simulation abort, the debug is easier • Data that is being loaded is echoed back to the user so the user knows what data is being used. • Component modules are linked to libraries. A change in the library module propagates to all vehicle models during execution. At this point in the review, I do not have adequate data to comment on the execution optimization of GEM-II. Linear interpolation modules from the standard Simulink library are used within GEM-II, thereby optimizing execution. If there are any non-standard user defined functions used within the GEM-II simulation model, the execution can be made considerably faster through the use of s-functions within Simulink. At the time of this review, no S-function were found in the model.	

Table 5. Charge Question 4		
Charge Question 4: Please comment on the clarity, completeness and accuracy of the intended output/results (CO_2 emissions or fuel efficiency output file).		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	The .csv output results are sufficiently comprehensive for the user who is not executing the program in MATLAB for research	Yes, a succinct report with .csv format will be used as output.

Table 5. Charge Question 4		
Charge Question 4: Please comment on the clarity, completeness and accuracy of the intended output/results (CO_2 emissions or fuel efficiency output file).		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	and design purposes. Presumably a report similar to the .csv is anticipated as the executable version output. In fact, to the manufacturer, who is executing this at time of sale within a larger accounting loop, a very succinct output would be sufficient.	
Reviewer 2	The data reports did not appear to be fully complete, but the accuracy of the output/results appears to meet reasonable expectations. The input and output structure of GEM was not finalized when released for peer review, however some samples of the output files were provided to give the reviewer a flavor of the potential structure. In my opinion, for completeness, the output file needs to include results for each different cycle and not only for the weighted aggregation of cycles. Some metrics can be added to the output file to facilitate troubleshooting and give the user a better perspective. As mentioned before, actual simulated speeds and a measure of deviation from the speed-distance trace would ideally also be provided for transparency of the results. Based on the validation results, accuracy with respect to measured data was provided and seems to be within 5%, which is acceptable output accuracy based on comparable modeling as well as real-world testing.	Phase 2 GEM will use the same output information to report certification as Phase 1 GEM, meaning that output file would only include the weighted aggregation of cycles for the sake of certification. However, the user does have the option to access the source code to find out more for those intermediate results, although the results from source code would not be allowed for certification.
Reviewer 3	The model outputs and results seem clear, complete and accurate. One caveat with interpreting or using the freight efficiency or load efficiency-based results lies in the use, further interpretation or extension of these results. Users might be tempted to "scale" the load-based results in an inappropriate fashion – for example, if the returned result for the computed carbon dioxide emissions is 100 gCO2ptm (grams CO_2 per ton-	For certification, GEM uses default payloads for each regulatory subcategory, meaning that the user would not have option to make any change on the payload, thus avoiding the issue mentioned by this reviewer.

Table 5. Charge Question 4		
Charge Question 4: Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	mile) for say a 30 ton vehicle over a specific cycle, there might be the temptation on the part of users to employ that same numerical result to predict the CO2 emissions for the same vehicle loaded to 40 tons over the same cycle. However this assumption is not correct, as the vehicle fuel consumption is a function not just of load or weight-related terms (rolling resistance, grade, acceleration etc.) but also terms that are invariant with load or weight (such as aerodynamic drag), and this is not reflected in an emissions per ton-mile result.	
Reviewer 4	The output data from a simulation execution is summarized in a spreadsheet, which is date and time stamped, allowing the user to verify that the output data corresponds to the simulation executed. The output data contains data on which technology improvement (weight reduction, vehicle speed limiter, single drive axle, par time single drive axle, low friction axle lubrication, predictive cruise control, high efficiency AC compressor, electrified engine cooling pump, extended engine idle reduction, automatic tire inflation) was assessed, engine, transmission type, fuel economy and CO2 emissions. The output data, summarized above, serves the original purpose of GEM-II, which is to enable users to demonstrate compliance with regulatory standards either without any modifications to the HD vehicle, or analyze the fuel economy and CO2 emissions, when one or more technology improvements are employed. However, information on the drive cycle is missing or not clearly identified. In addition, key plots of vehicle tracking the drive cycle, engine operating speed-torque points over the drive cycle,	GEM is a certification tool, and as such produces simplified results, which can not only be easily connected to the agencies' certification tool box for compliance, but also can be directly linked to the manufacturer's information technology system. For more comprehensive outputs and plots, the user has the option to use the Matlab/Simulink version of the source code to provide a better understanding of the results. GEM as a certification tool is not meant to be used as a development aid. Again, the results from source code would not be allowed for certification.

Table 5. Charge Question 4		
Charge Question 4: Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	engine efficiency contour plots, transmission operating points, and other plots that assist OEMS to further fine tune the powertrain and improve fuel economy/ CO2 emissions in case of non-compliance. It would be desirable to have the results of the energy audit summarized in the output file. The date stamp column is appropriate for the user to cross check simulation runs.	

Table 6. Charge Question 5		
Charge Question 5: In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	Words of caution may help in presenting GEM to the user and to the public. It is important to state that GEM has acceptable accuracy in predicting the fuel efficiency of a specific vehicle under specific circumstances. However, it is equally important to state that if GEM is used to compare two competing, but very different, technology packages, it may not have the fidelity or granularity to evaluate which is better. GEM may not determine the relative difference between the two with high fidelity, and that relative difference will depend on the vehicle vocation or test cycle used. Although modeling test weights were provided for the example vehicles, there was no quantitative discussion of choice of test weight for GEM. Test weights receive only brief mention in the supporting documentation. It is possible that within vehicle classes, or across regions with different topography, engine size	Test weight is set to a default value for each regulatory subcategory, which means that the user would not have option to make changes. This is necessary, because allowance of different test weights per vehicle can result in numerous standards for the same class vehicle, which would be challenging for the purpose of compliance. The agencies provide details regarding the proposed payloads and test weights in Chapter 3 of the HD Phase 2 Draft RIA and seek comments regarding the weights in the preamble.

Table 6. Charge Question 5		
Charge Question 5: In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	may be selected based on the anticipated load. The distance based strategy shows an appreciation for this issue, but some compensation with test weight for engine size could be considered. Perhaps test weights could be selected so that the time to complete the route remains within reasonable bounds for more lightly powered vehicles, but at least that highly powered vehicles are acknowledged to be appropriate for some occupations, loads or regions. The vocational tractor option in Phase I is not a comprehensive solution.	
Reviewer 2	Phase 2 GEM could generate two different output reports. One that only includes the most relevant information on an aggregated format and is used only for compliance purposes, and a second one, that is very detailed and includes results disaggregated by cycle and other relevant information that may help the users to troubleshoot their results, learn the inner workings of the model and potentially suggests enhancements to it. I suggest including a summary of the energy audit in the output. Also, provide the average engine efficiency over the cycle for the different test cycles, as well as the ratio of average engine efficiency to maximum engine efficiency, which is an indication of how well the transmission parameters are matched to keep the engine operating near its peak efficiency range. The output file provides some basic "sanity checks" such as number of shifts, ratio of number of shifts to number of gears in the transmission, distance traveled, and ratio of actual time to target time. Please also provide ranges of valid or acceptable values for these parameters so the user can be aware of any	GEM is a certification tool, and as such produces simplified results, which can not only be easily connected to the agencies' certification tool box for compliance, but also can be directly linked to the manufacturer information technology system. For more comprehensive outputs and plots, the user has the option to use the Matlab/Simulink version of the source code to provide a better understanding of the results. GEM as a certification tool is not meant to be used as a development aid. Again, the results from source code would not be allowed for certification.

Table 6. Charge Question 5		
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Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	potential issues with the simulation. A further step that could allow the tool to be much more useful would be to allow users to input their own cycles as is currently done with VECTO[6] (Vehicle Energy Consumption calculation Tool) model in Europe. The VECTO tool has a "declaration mode" for compliance, and an "engineering mode" which offers the ability to edit inputs and allow users to explore what the tool can do. This would be critical for transparency and follow the best practice as seen in the Europe situation. It would also be highly useful for individuals in the heavy-duty vehicle supply chain to explore the variation of the results with respect to real-world duty cycle factors. Especially considering the very diverse use of heavy-duty vehicles in local, regional, and long- distance conditions, this capability would allow dealers and fleet managers to gauge how fuel consumptions for particular relevant driving patterns differs from the cycle. This would help ensure the technologies that are more suited to particular duty cycles are being selected in the market place, and it would also help overcome the prevailing market barrier, whereby knowledge, data, and confidence on truck efficiency has been limited.[7] References: [6] See Luz et al (2014) http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/final_report_co2_hdv_en.pdf [7] See Roeth et al (2015) http://www.theicct.org/hdv-technology-market-barriers-north-america	

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Charge Question 5: In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 3	The version reviewed here does not include the graphical user interface (with "pull-down menus") described in the instructions. The ability to modify input parameters and vehicle attributes will improve the user experience, while obviously presumably not impacting the model outputs. Due care and attention should be paid to the number of significant digits presented in the output results. For example, in the results presented from a single specific simulation (shown below): >> GEM_Phase2_Idle_55_65_CARB_HHDDT_Transient Distance = 32.414 mi Fuel Consumption = 5.4059 gallons Fuel Consumption = 17184.1217 grams Fuel Economy = 5.996 mpg Fuel Consumption = 530.140 g/mile CO2 Emission = 1697.77 g/mile The number of significant digits in the model simulation outputs presented above (some of which are directly related through derivation or calculation) varies from 4 to 9. This does not meet recommended practices in the presentation of results and data. Moreover, industry experience in the measurement of real-world fuel efficiency during over the road truck testing dictates that measured fuel consumption variations of less than 1-2% should not be considered significant or compelling, and this level of variation could correspond to variations in the 2nd or 3rd significant figures in fuel consumption in most cases.	The agencies have consulted with all major manufactures on whether a graphic user interface (GUI) needs to be developed. At this time, none of them support this idea. The reason is that a GUI would prevent the GEM output from being integrated with their internal information technology system. At the same time, a GUI would provide convenience to those individual user or small entities for use. In order to compromise this issue, the agencies decide not to propose a GUI. Rather, the input file is designed in such a simple way that the individual users can easily use it for their own purpose, and an interactive Excel spreadsheet will be made available as mentioned previously. The number of the significant digits shown in the output screen is not the same as those in certification output file (.csv). It should also be noted that the same output format is used for light duty vehicles where the magnitude of the numbers is much smaller and therefore the significant digits are fewer. No attempt was made to tune this output, which is not part of the certification process, for heavy duty test results.

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Charge Question 5: In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?		
Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 4	The following modules will enhance GEM-II: • A module that is able to create the input data for a GEM-II execution from a user provided spreadsheet with pre-defined tabs for the engine, transmission, drive cycle, vehicle parameters, and technology improvement. Users are more familiar with spreadsheets than the Matlab environment. • A GUI module that guides the user to create a HD vehicle model. • A module that allows users to select plots of key component performance. These plots may be summarized in the output spreadsheet data file. • A more detailed explanation of all the user provided data "target.X" and the various choices available for each of the user provided data. For example, what are the choices that the user has for the variable target.veh_style ? • GEM-II execution takes place within the Simulink environment. During execution, no feedback is provided to the user on the status of the simulation. The user is waiting on a blank screen – Percent complete of the simulation and which drive cycle is being executed would be useful feedback for the user. • Predefined sample input data for all class of vehicles to assist users to easily modify them if necessary, since some users may not be familiar with Matlab. • The ability to turn on the feed forward term for the driver model in case of tracking problems in drive cycles with grade.	Many comments made by this reviewer are very helpful in terms of the Matlab/Simulink version of GEM. As pointed out earlier, only the executable version of GEM is allowed for certification where the Matlab/Simulink environment is not needed. Because of that, the user has no option to make any model constant modifications. A GUI is helpful for individual users. However, it may not be helpful for large vehicle manufacturers where they need to connect their information technology system with the output of GEM. The agencies attempt to balance the needs of individual users and large organizations. The combination of the proposed input file and GEM User Guide should be as user friendly as a GUI.

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Reviewer Name	**Reviewer Comment**	**EPA Response to Comment**
	• The ability to model accessory power draw as a function of engine speed and engine temperature. The engine cooling fan power cycle will affect fuel economy and CO2 emissions.	

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1	8	1	Axle lookup table is a better approach	The agencies note the comment but determined no revisions are required to the documentation
	8	2	"Brakes" Addition of the inertia component to axle is curious/ a curious description. This is rather a retarding torque. Perhaps the inertia becomes a force if MATLAB is viewed over time steps. I was confused by this language.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM.
	10	2	It would be good to see (as well) the equivalent to Figure 1-3 with the proposed locked shifting strategies in GEM, rather than actual strategies as discussed on p. 10.	Some of the comparisons are shown in Table 4.
	16	2	Need to be cautious about claims in modeling changes. Effect of change in Crr is clear, but GEM may have difficulty with relative accuracy in changing transmission type.	The agencies note the comment but determined no revisions are required to the documentation
	16	2	Note in presenting these agreements that Crr or Cd changes are entered as dynamometer A-B-C coefficients, and these are not real world	The agencies note the comment but determined no revisions are required to the documentation

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			measurements. Essentially the dynamometer is partially modeling these effects.	
	17	Table 1-3	And the figure. Note that the 1.8% error represents a 17% error based on the difference, if this figure is intended to show the accuracy of predicting differences rather than absolutes.	The agencies note the comment but determined no revisions are required to the documentation
	18	2	GEM is using automated shifting, essentially, for both MT and AMT, and this will be used (with PI control pedal) for impact assessment. Yet this paragraph brings human drivers to the fore. Philosophically, that the human drivers are the truth and the accuracy of revenue service, more than the model or powertrain cell.	The agencies note the comment but determined no revisions are required to the documentation
	19	Fig 1-9 to 1-13	Are these with default or manufacturer's shift tables?	Yes.
	22	Table 1-4	Little or no shifting occurs in the 55 and 65 cycles. That should be stated.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	23	End of page	Text should explain in a little more detail how these powertrain tests may be inserted into GEM	The agencies note the comment but determined no revisions are required to the documentation
Reviewer 2	2	2	The list of key technical features may include the fact that the new model uses distance-based cycles instead of time-based cycles, and the fact that test cycles now include road grade.	It is a distance-base model
	2	2	The claim "more stable engine idle speed controller" is not discussed in the text. Some metric or quantification of what is meant by "more stable" needs to be provided.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	2	3	Regarding "substantial effort has been put forth to	It is mainly used for internal use.

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			accurately track and audit power flows through the model to ensure conservation of energy" The report lack details about the energy audit. Was the energy audit developed just for internal quality control or is it going to be provided to the end users in an output file?	
	3	1	Regarding "the road gradient has been modified to accept a road grade that varies as a function of distance traveled" Please introduce the concept of distance-based versus any pros/cons of the new method and why did you change the approach.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	3	2	Driver subsystem. This section (1.2.2.2) is not clear to the reader and, in my opinion, needs rewriting. There are various confusing statements such as "the feed forward calculations using drive cycle accelerations and vehicle mass have been removed". The section also mentions (page 4, paragraph 1) that a ratio of speeds (which is non-dimensional) is integrated to produce the current cycle position (which has units of distance), which is dimensionally incorrect. I recommend showing the equations to avoid confusing the reader. Regarding the statement "the addition of distance compensation allows all simulated vehicles to complete an equivalent trip such as traveling from point A to point B" Does that mean that without distance compensation the vehicles would not complete the trip?	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	3	2	How were the proportional and integral constants of the PI controller estimated? Is the same driver subsystem used independently of transmission	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			choice? How was the look-ahead feed-forward control implemented?	
	4	2	Consider removing the mention to the "variant power train architecture" since it is not mentioned anywhere else in the report.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	5	1	Please clarify that the engine map is not a pre-determined parameter as in Phase 1 GEM, but a user-defined input.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	5	3	For consistency with previous section, please show the proposed constant power loss magnitude of electric subsystem.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	5	4	Please change "four different variants" for "three different variants" (MT, AMT, AT).	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	11		There is an apparent incongruence in Page 5, paragraph 4, which mentions that each transmission "features a unique control algorithm matching behaviors observed during vehicle testing" however, in Page 5, paragraph 5 it is mentioned that "all of the transmission models use an auto shift algorithm to determine the operating gear over the cycle". Are the auto shift algorithm parameters changed based on transmission type? Is there really a unique control algorithm for each transmission type?	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	5	5	The "auto shifting optimizer" needs proper documentation. How does it work?	A reference paper (Newman, K., Kargul, J., and Barba, D., "Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation," SAE Int. J. Engines

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
				8(3):2015, 2015, doi:10.4271/2015-01-1142.) has been added into Draft RIA chapter 4 for more information
	6	1	The clutch model is a key new addition and lacks proper documentation. Please support claims such as "realistic actuation durations and more accurate physics of torque conservation and lockup behavior" with data.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	6	2	Please clarify what you mean by "This layout is more similar to a manual transmission, but the application for a planetary gearbox is a reasonable approximation as this type of gearbox can utilize a variety of topologies" is confusing to me.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	8	2	The statement "The brake model also adds a rotational inertia component to the axle" is misleading since the inertia of brakes is set to zero in GEM.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	9	2	Please provide a table with a complete list of pre-defined and user-defined parameters. There is no need for specific values, just the list of parameters.	It is included in the NPRM
	12	1	Description of test condition number 6 reads, "Run a new set of road load coefficients to represent a vehicle configuration optimized for fuel efficiency for each vehicle that was tested." To be consistent with the other test conditions described please quantify the reductions in rolling resistance, aerodynamic drag, and mass for this	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			particular "optimized package" case.	
	13	Figure 1-3 to 1-6	In the legend, it is not clear if the 55mph and 65 mph tests contain grade or not. Also, the "utility" cycle is not described in the text.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	15	Figure 1-6	Although is mentioned in the text, it seems that the refuse truck was not tested under the refuse cycle. Also, it seems that it was not tested under different test conditions as the remaining vehicles. Any reason for this? Please explain.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	16	1	Change "numerically" for "numerical."	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	18	2	The statement "In some cases, it is hard to quantify which method, vehicle simulation or chassis dynamometer test, is more accurate" is very misleading. The chassis dynamometer test although imperfect, is a measurement and it was treated as a "true" value in the validation process (Figures 1-3, 1-5, and 1-6). Accuracy can only be measured in reference to a true value. The chassis dynamometer test was selected as such and the model cannot hope to have better accuracy than the test.	Added SwRI technical research workshop as one of the references to Draft RIA Chapter 4. (US EPA, "Technical Research Workshop supporting EPA and NHTSA Phase 2 Standards for MD/HD Greenhouse Gas and Fuel Efficiency — December 10 and 11, 2014," http://www.epa.gov/otaq/climate/regs-heavy-duty.htm)
	18	3	In the statement "GEM is capable of capturing the impact on the total vehicle CO_2 emissions and fuel consumption due to any technology improvement" the word "any" is misleading since the validation effort was only done over aerodynamic, rolling resistance and mass parameters. Moreover, there is certainly a set of	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			technologies that GEM is incapable of model.	
	17	Table 1-3	Correct the numbers on the "Delta" column. Due to rounding it is not evident that the column represents the difference between the two previous columns. For example in the fourth row we have 3.9% - 4.9% = -0.9%. In the same Table, please calculate the relative error (consistent with Figure 1-8). Is this relative error more relevant than the "delta"? What is the maximum acceptable relative error?	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	22		Please add a table that summarizes the technologies captured by the simulation and the technologies that are not captured but are accounted for via drop-down menus. A third (optional) column may include technologies that currently are not either simulated, nor recognized by drop-down menus but potentially may be included in future regulations.	We have detailed the technologies included as inputs to GEM and technology improvement inputs (drop-down) in the HD Phase 2 NPRM preamble. We welcome comment on other technologies that would only be considered as part of the innovative technology credit program and therefore not simulated or recognized by the drop-down menu.
	22	Section 1.4.1.1	Regarding "As described in Chapter 1.2.2, one of the major changes in the HD Phase 2 version of GEM is to allow manufacturers to enter their transmission gear number versus gear ratio" Chapter 1.2.2 does not mention that fact. Please check throughout the report to avoid issues with these self-references.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	23	1	Regarding the statement "Manufacturers also have an option to select the type of transmission, which is either manual or automatic" It is not clear if transmission type is a required input or an	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			optional input. Also, the user should have three options (AT, MT, and AMT), not just two.	
	23	Table 1-4	Table heading should mention that the results are from simulations in GEM, not measurements. Also, it is not clear if the 55mph and 65mph cruise contain grade.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	23	4	The report mentions that due to lack of data, DCT, DCT with TC and Allison TC-10 AT transmissions were not validated. That assertion implies that MT, AMT and AT were validated. Since transmission technologies were not tested at the same level of detail as road load reduction technologies, it is important to acknowledge the different level of validation between transmissions and road-load reduction technologies.	The agencies note the comment but determined no revisions are required to the documentation
	23	Last Paragraph	Regarding DCT and other transmission types not included in the model, the report says, "The manufacturers still have the options to use powertrain dyno tests to quantify the benefits of these or any other special transmissions". It is not clear if the results of the power train tests are going to be used to correct the GEM simulation results or are going to replace the GEM simulation results altogether. Please clarify.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	24	1	Regarding OEM overriding the axle efficiency input, "the inputs would be determined by using the prescribed test procedure" It is not clear which test procedure is the report referring to. Please add a reference to such procedure.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	24	Last	Rolling resistance coefficients are usually expressed	The text has been corrected (or clarified)

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
		Paragraph	in units of kilograms per metric ton (1 t = 1,000 kg). The units used (kg/ton) may imply short ton (1 ton = 2,000 lbs.). Please correct and be consistent throughout the document.	in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	25	1	The "Regional", "Multi-purpose", and "Urban" composite duty cycles are not described in the document.	More can be seen in Chapter 3.4.2.3 about idle cycle as stated in the same paragraph
	25	3	Please support your statement, "We concluded that for the 55 mph and 65 mph duty cycles, GEM's interpolation of steady-state data tables was sufficiently accurate versus the measured results" What was the observed accuracy of using steady-state maps for the 55 and 65mph cruise cycles? How much accuracy is sufficient?	This statement is based on the engineering judgment.
	25	3	The 55mph cruise is named "urban highway with road grade", the 65mph cruise is named "rural highway with road grade, and the ARB transient cycle is named "urban local". Please try to use consistent names throughout. Also, since the cruise cycles in Phase 1 were time-based and did not include road grade, the Phase 2 cruise routes (distance-based with grade) are not equivalent to them and using the same name is misleading. I think a distinction can be made by using the term "route" for the distance-based tests and "cycle" for the time-based, or simply name them "55mph cruise with grade" and "65mph cruise with grade".	The agencies note the comment but determined no revisions are required to the documentation
	29-30	Table 1-6 & 1-7	Automatic transmissions have the same efficiency for all gears (98%), and such efficiency is equivalent to that of manual and automated manual	We chose this based on the comments from manufacturers' input plus our engineering judgment.

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			transmissions in direct drive. Was this advantage observed during testing? If possible, please document with measured data showing the benefits of AT over MT in terms of gearbox efficiency.	
Reviewer 3	1		Use "dynamometer" and not "dyno"	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	Et seq.		Use "Phase 2" and not "Phase II"	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	5	1.2.2.3.1	Use "watts" or "W" and not "Watts"	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	5	1.2.2.3.1	"it may o make use" requires clarification	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	7	1.2.2.3.3.7	"With the new gear engaged the clutch is reengaged and the engine is again allowed to operate at full load." This statement presupposes that the transmission was shifting under full engine load, which is not necessarily the case for high power engines under benign operating cycles.	The agencies note the comment but determined no revisions are required to the documentation
	7	1.2.2.3.4	"This includes drive shafts as well as driven and passive axles, consisting of a differential, brakes and tires." Passive axles will not ordinarily include a differential, only driven axles will.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	8	1.2.2.4	"The vehicle system consists of the chassis, its mass and forces associated with aerodynamic drag and changes in road grade". Why "changes in road grade"? Any constant road grade (other than zero)	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
			will have an effect on the apparent vehicle load, and not just changes in grade.	
	9	1.2.2.4	"computes acceleration [not accelerations] from the input force and equivalent mass which is integrated to generate vehicle speed and distance traveled"	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	9	1.2.3.2	Use "Matlab" or "MATLAB" and not both.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	10	1.3	"Validations use all actual vehicle variables conducted at Chassis dyno cell," needs editing.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	11		Ref. 3 is not the SwRI report as stated. It is an ASME Technical Paper.	The Technical Paper is the report
	12		A +-15% variation in aerodynamic drag, for example, is unlikely to span the full range of expected values in the future for HD vehicles. Presumably aerodynamic modifications to Class 8 vehicles may result in significantly lower drag coefficients, or drag products (CdA)	This was just for the purposes of the tech study, these are not GEM limitations
	13	1.3.2	For the Class 8 T700 tests, at high fuel efficiency, the GEM model appears to consistently under-predict the actual measured vehicle fuel economy. This consistent offset is of concern. The reverse is observed for the Class 6 truck tests.	In the technical research workshop held at SwRI in December, 2015, the testing variability is discussed in details. It is very challenging to validate GEM for those highly transient cycles for a heavy truck.
	20	Fig 1-11	Caption is incorrect.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	21	Fig 1-13	Vertical axis incorrect unit designation.	It is NM for torque
	22		Do not use the term "aero drag". It should be "aerodynamic drag".	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD

Table 7. Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"				
Reviewer Name	**Page**	**Paragraph**	**Reviewer Comment**	**EPA Response to Comment**
				Phase 2 NPRM
	22		"tire radius" should be "tire rolling radius" or 'effective radius'.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
Reviewer 4	5	2	The last sentence reads "If a manufacturer uses a hybrid powertrain for the power take-off devices, it may o make use of ….". The "o" after may is a typo.	The text has been corrected (or clarified) in Chapter 4 of the Draft RIA to the HD Phase 2 NPRM
	3	2	Distance compensation is critical for all vehicle simulations – Therefore, this is a good feature that has been implemented in GEM-II	The agencies note the comment but determined no revisions are required to the documentation
	6	4	Please explain what is included in spin losses, since this may not be clear to all OEM users.	The agencies note the comment but determined no revisions are required to the documentation
	9	3	The GEM-II executable is very appropriate for users who are not fluent in the Matlab/Simulink environment. Further, the executable prevents users from making any changes to GEM-II to support compliance.	The agencies note the comment but determined no revisions are required to the documentation

Table 8. Specific Observations on Electronic Model Entitled, "GEM Tool"				
Reviewer Name	**Input**	**Variable**	**Reviewer Comment**	**EPA Response to Comment**
Reviewer 1			No Specific Comments or Observations Provided.	
Reviewer 2			File: "GEM_run_postproc.m" Lines: 104 to 108. Potential issue: It seems to me that the equation is not dimensionally correct (I might be wrong). Additive terms should have the same units and the equation seems	The equation, while lengthy, is correct. Simplified, the equation amounts to grams/hour * hour/mile which equates to grams/mile.

Table 8. Specific Observations on Electronic Model Entitled, "GEM Tool"				
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			to be adding gCO2/h terms with gCO2/mile terms. Please check for missing terms and/or appropriate use of parenthesis.	
			File: "GEM_run_postproc.m" Line: 101. The calculation performed for case 4 is identical to the calculation performed for case 3, making it redundant. Please eliminate case 4 (neutral idle with start/stop), or correct the equation to account for a 90% reduction in neutral idle emissions (not drive idle emissions).	This is correct, for certification neutral idle and start/stop will not be credited simultaneously, only the start/stop credit is available. This code is from the evaluation phase of GEM development.
		"vehicle.chassis. frontal_area_m2"	The name is misleading. Please rename to "drag_area". Drag area is CdA, aerodynamic drag coefficient is Cd and frontal area is A.	The model supports separate variables for Cd and Area. For certification, we set the Cd to 1.0 and apply the Cd*A to the area variable. This does not affect simulation results.
			File: "load_GEM_params.m" Lines: 76 to 85. These equations set weight reduction penalties for spark-ignited CNG (525 lbs), compression-ignited CNG (900 lbs), and compression-ignited LNG (600 lbs). Please set a weight reduction penalty for the missing case: spark-ignited LNG.	We are seeking comment on the weight penalties associated with natural gas vehicles in the preamble to the HD Phase 2 NPRM. We will adjust the values accordingly for the final version of GEM, based on the comments received.
			File: "load_GEM_params.m" Line: 94. I am confused about the variable "vehicle.chassis.mass_dynamic_kg" as defined here is a constant. However, during the simulation (variable: datalog.vehicle.dynamic_mass_kg) the equivalent mass of the rotational components vary depending on the active	The chassis.dynamic_mass_kg represents the weight of the chassis ("static_mass_kg") plus the effective mass of the rotating inertia of the tires/wheels (125 lbs mass per wheel as consistent with other EPA test procedures). The upstream inertias are calculated dynamically during model execution, as noted, and added to the chassis.dynamic_mass_kg to determine the vehicle's total effective inertia. The datalog

Table 8. Specific Observations on Electronic Model Entitled, "GEM Tool"				
Reviewer Name	**Input**	**Variable**	**Reviewer Comment**	**EPA Response to Comment**
			gear.	variable represents the total vehicle inertia during simulation, not just the inertia of the chassis.
			File: "load_GEM_params.m" Lines: 117 and 143. It is not clear what exactly the variables "transmission.autoshift.cost_map" and transmission.autoshift.required_cost_benefit_ratio" represent, and how are they used in the model. Other features such as "restrict skip shifts", restrict shift parity", "disable coast saving downshifts" are not well documented in the .m files or in the report.	These features are not user inputs but are described in a technical paper, SAE 2015-01-1142.
			File: "load_GEM_params.m" Line: 131. The calculation of "Transmission.gear.inertia_kgm2" involves a multiplication by 0. Therefore it would produce an array of zeroes. Also, assuming that the value of 0 is changed to a finite constant, it seems that the model is assuming the same inertia value for all the different gears. Is that simplification accurate?	For the transmission in question, the total inertia is represented by the common input and common output inertia, the inertias referred to are the "gear specific" inertias which for an AMT or MT are set to zero since all gears always spin with the input or output. Since this is not a user input the default value makes little difference for certification purposes since all users will use the same value.
			File: "load_GEM_params.m" Line: 134. The calculation of "transmission.gear.spin_loss_torque_Nm" involves a division by a factor of 3.73 for all the transmissions that are not C78_AMT. I am wondering what that factor represents. Also, if that factor is still	The 3.73 is a scale factor which scales the default Class 8 spin losses down to a level comparable to the automatic transmission while maintaining the same loss trend as the Class 8 AMT with respect to speed. The default transmission losses will receive additional scrutiny between now and the final rule. In addition the peer review does not necessarily

Table 8. Specific Observations on Electronic Model Entitled, "GEM Tool"				
Reviewer Name	**Input**	**Variable**	**Reviewer Comment**	**EPA Response to Comment**
			valid for a potential C78_MT transmission.	have specific default values for every transmission type by capacity (LD versus HHD, etc).
			Energy Audit. Net system kinetic energy change is 0 kJ, which is the result of the test cycle starting and ending at 0 mph speed. The test cycle seems to start and end at the same altitude (symmetric grade profile traveled at constant speed), so one can expect the net system potential energy change to be 0kJ as well. Since both kinetic and potential energy are conservative and not dissipative forms of energy, I was confused about the energy audit accounting for energy "consumed" by gradient at about 17% of the losses for a tractor-trailer. Checking the equations, it seems that the energy audit is performed only for positive tractive loads. If that is the case I am confused about the energy consumed by the brakes at about 7% of the losses for a tractor-trailer. They should be really low if one is only considering positive tractive loads. The brakes are mostly applied for negative tractive loads (e.g. driving downhill). Am I missing something here?	For auditing purposes, the potential energy changes are split between "Energy Consumed" (going uphill) and "Energy Provided" (going downhill). In the case of a driving cycle which starts and ends at the same altitude but has some gradient in-between you will see equal (within model tolerances) entries in both of these audit categories. All of the "Energy Consumed" audit values represent energy sinks, the brakes are included among these since they dissipate kinetic energy. In any case, the audit report is for internal use only and does not represent a user or certification output.
			Why the weighted average speed (weighted_avg_speed_mph) used in post processing (file: "GEM_run_postproc.m") is based on the target speed-distance trace and not in the actual simulated speed-	For tractor-trailers the idle weight is zero and the simulation grams/mile are multiplied by target mph and also divided by target mph so what remains is simulation grams/mile which will reflect the modeled performance (or under-performance) of the

Table 8. Specific Observations on Electronic Model Entitled, "GEM Tool"				
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			distance trace? This decision has implications for underpowered vehicles that deviate substantially from the target trace since their actual average speed may differ substantially from the target speed. This also has implications for the calculation of idle fuel rates for vocational vehicles since the conversion factor from idle fuel rate in [kg/h] to [kg/mile] is the weighted average speed.	vehicle. For vocational vehicles the same is true with regard to the simulation grams/mile over the drive cycles. Idle consumption takes places at zero speed and is measured in grams/hour so there is a conversion factor required to obtain grams/mile. The target weighted average speed represents that conversion factor and does not alter the modeled vehicle performance (or under-performance) over the drive cycles.
Reviewer 3				
		Aerodynamic drag	-- Audit data for GEM_Phase2_Idle_55_65_CARB_HHDDT_Transient drive cycle – "Energy Consumed by Cd" should refer to "CdA" and not "Cd" alone.	True, but the audit report is for internal use only and does not represent a user or certification output so the shorthand here is of little importance.
		Engine Accessories	Engine Accessories = 846.16 kJ 0.23% It seems as though engine accessory loads are under-accounted for in this implementation of the model – a 0.23% loss for a full transient cycle seems inappropriately low.	For peer review, the accessory load is set to 1300 W combined mechanical and electric load for all vehicle classes. The agencies are seeking comment on the predefined values in GEM in the HD Phase 2 NPRM preamble and will make the necessary adjustments for the final version of GEM.
			Usable System Energy Provided = 373988.49 kJ Engine Energy = 309402.35 kJ Engine Efficiency = 42.08 %	The maps provided were mathematically generated and do not necessarily represent actual fuel maps. In any case this would represent the total efficiency over the drive cycle. These audit results are not user or certification outputs and will not be available

Table 8. Specific Observations on Electronic Model Entitled, "GEM Tool"				
Reviewer Name	**Input**	**Variable**	**Reviewer Comment**	**EPA Response to Comment**
			This integrated "engine efficiency" is high for the average efficiency expected across a fully transient cycle – does this refer to the peak engine efficiency encountered?	during certification.
Reviewer 4			Avoid taking the derivative in the Simulink models. This can cause instabilities if the signal fluctuates rapidly	Point taken, the use of derivative blocks is minimized in GEM.

E. INDIVIDUAL PEER REVIEWER COMMENTS

Peer Reviewer # 1

Peer Review Comments on EPA's Heavy-Duty Greenhouse Gas Emission Model (GEM): Phase II and Supporting Documentation

I. GENERAL IMPRESSIONS

The purpose of GEM in determining standards, providing a compliance tool, and estimating real-world benefits is clearly articulated. The proposed Phase II GEM tool has evolved substantially from the Phase I version, particularly by allowing additional user inputs that are necessary to acknowledge fuel efficiency design improvements. As a compliance tool GEM should seek to account for all technology advances and differences, yet remain simple to execute and employ readily-measured and well-defined input variables. The Phase II GEM model has reached a reasonable compromise between these conflicting goals, and this made clear in the narrative. The overall architecture is sound, the present component models are appropriate to the task in nearly all cases, and they are clearly described. The model yields credible results and credible responses to input variable changes. The overall model predicts fuel efficiency to within 5% of experimental measurements, and a clear summary of these comparisons is presented. However, the material does not address quantitatively the experimental error that is likely in these comparisons, and measurement errors associated with rolling resistance and drag are not included in the data comparison. Overall agreement with experimental data (as vehicle fuel economy) does not validate each component model to the same degree, and this should be acknowledged more clearly. As one example, overall fuel economy data are used to compare a component model with a fixed efficiency value. The difference overall was only 1.67%, but this represented more than a third of the losses for that component. The move to a distance-based strategy is justified and well-described, and represents a laudable advance. Addition of several transmission models is presented, as are thoughts on the addition of transient adjustment factors. Little is said of the "powertrain variant architecture," although this may prove important for integrated powertrains with or without a hybrid component. Transient Adjustment Factors are not yet finalized, and transient operation may warrant more than a single correction factor approach.

II. RESPONSE TO CHARGE QUESTIONS

1. Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?

Throughout his review, except where different fuels are mentioned, fuel efficiency improvement and GHG reduction are considered to be synonymous.

Beyond the need for assurance of compliance is the need to reduce fuel use and climate change emissions from heavy-duty vehicles in revenue use. A successful EPA approach must be examined from two perspectives. First, it is necessary that the approach yields well-defined, unambiguous results to allow a manufacturer to compare against a standard without the process being unreasonably onerous. Second, it is necessary that that the vehicle attributes and behaviors embodied in the certification process are substantially representative of real world circumstances. These two necessities are often in conflict, because the real world scenario is complex, variable, and long in duration, whereas the standard must be concise and precise. The conflict is far greater in the heavy duty trucking arena than for light-duty vehicles or rail because truck architectures vary widely, and are used in an even wider fashion.

Employing a model such as GEM to assure compliance provides some relief in the conflict described above because the model can be executed for a variety of activities and scenarios without excessive cost of time and resources. However, as the model is challenged to predict these varied (and emerging) scenarios with fidelity, the model complexity rises. As a result, the empirical tables or computational sub-models needed within the model grow in number and demand substantial engineering time to prepare and verify. One might argue that "the more one models, the more one measures," recognizing too that precise test protocols must accompany each measurement.

Compromise is necessary between four fundamental needs:

1) Relevance of the model to real world truck operation.
   Else the real world improvements will not match the changes in standards.
2) Accuracy of the model in predicting measured fuel efficiency (and GHG production).
   Else confidence in the model will be lost and the compliance will become artificial.
3) Accuracy of the model in predicting differential effects of technology changes on fuel efficiency (and GHG production).
   Else the drivers for technology advancement will be lost
4) Control complexity and cost of modeling and compliance.
   Else the cost transferred to the consumers will be inappropriate.

The overall new GEM approach shows awareness of these necessities, and reaches a reasonable compromise. However, when some parameters are fixed by the agency, manufacturers may be discouraged from pursuing certain development opportunities in the following way. Both future fuel pricing and future fuel efficiency standards are unknown. If high fuel prices transcend the standards, then manufacturers will pursue every cost-effective tool to reduce fuel use. However, if fuel prices are low and are not the driving force, and the GEM approach offers default values for factors such as engine transient adjustment factors or transmission efficiencies, some opportunities for real world reduction may be left on the table. GEM cannot rely on economic drivers to address technology advances that are not modeled.

GEM is a vehicle-based tool that is geared towards road-load demands rather than engine-specific ("%load" and "%speed") demands. Only the new distance-based cycles give a nod toward engine power. Criteria pollutants are still characterized using a paradigm based on engine rated output. Allowing different measurement methodologies for efficiency and criteria pollutant production will open a window for separate hardware and software optimization for each test. This may demean the benefits of the separate standards to some degree: in-use compliance for criteria pollutant measurement will not close this gap because measurement allowance for criteria pollutants reduces stringency for criteria pollutants.

2. Please comment on the appropriateness and completeness of the contents of the overall model structure and its individual systems and their component models (i.e., using the MATLAB/Simulink version), if applicable, and considering the following:

a) Elements in each system used to describe different vehicle categories;

The proposed GEM Phase II model represents a substantial advance over the model used to implement the first phase of truck efficiency legislation, and encourages more technology advances from manufacturers in consequence. Improvements in truck efficiency are based primarily on reductions in aerodynamic drag, tire rolling resistance and engine brake specific fuel consumption, and this was recognized in the first GEM model. Practically, there is less to be gained from aerodynamic improvements in most vocational truck operation than in long haul trucking and the GEM model as presented neglects vocational truck aerodynamics, and the modelers are right to exclude aerodynamic parameter entries for low speed trucks. However, the overall GEM structure is capable of modeling aerodynamic improvements for niche vocational designs, and has the flexibility to extend beyond the present exclusion of the drag coefficient. In this way, the capabilities of the model, as received, will be far greater than the executable version that is finally used for compliance.

A major theme in the industry is that efficiency gains are significant from design integration, particularly powertrain integration. But it is understood that combined powertrain control is proprietary. The supporting language might address this more clearly, noting that the GEM model employs just steady-state maps and a defined set of gear ratios, and cannot predict the benefits of more sophisticated integration. In a similar fashion GEM cannot predict the benefits of learning algorithms, look-ahead strategies and intelligent vehicle systems for the optimization of powertrain efficiency on specific routes. These are emerging approaches, but it is acknowledged that it would take great effort to configure GEM to deal with these details and it would be difficult to assure their generic benefit in revenue service. GEM has some check-a-box options proposed for features that cannot be modeled.

The model, as provided, was oriented to diesel engines. The shift strategies also considered the engine torque curve for execution. Naturally aspirated gasoline, boosted gasoline and natural gas engines are likely players in the next five years and may warrant separate and careful consideration because their characteristics, torque curves and efficiency maps differ substantially from the diesel engine properties.

b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;

MATLAB/Simulink remains an excellent basis for the GEM model. It is well suited for the exploratory and development framework, as well as the production of a more limited executable model.

GEM may be viewed on three levels. At the highest level, the MATLAB/Simulink platform allows GEM to be anything it chooses, with the addition or alteration of modules and component models. At the second level, there is the model provided for review, which has the innate ability to deal with a wide range of cycles and truck configurations. At the lowest level will be the final executable version, where certain parameters are fixed, and where the duty cycles are chosen for determination of compliance. Only the second and lowest levels can be considered in this review.

This GEM model is being produced at a time where engine control strategy development and integrated powertrain controls are advancing rapidly. Also, transmission options are now far wider than in the earlier GEM model, where unsynchronized manual, synchronized manual and traditional automatic transmissions dominated the marketplace. GEM is challenged in modeling and giving credit for the technology subtleties that will emerge in the marketplace over the next five years.

The use of distance, rather than time, as a basis for the test cycles represents a great and important advance. It was widely recognized two decades ago that light duty automobiles were capable of far more aggressive performance than was embodied in the FTP-75, although the FTP-75 was used as the norm, and still embodied allowances for vehicles that could not follow its modest accelerations. In the heavy-duty arena sustained use of full engine power both on grades and during acceleration is the norm. All else being equal, a more powerful truck will complete its duties in less time than an underpowered vehicle, and often the more powerful choice represents the overall economic optimum. However, the more powerful truck will spend less time at full power, and will enjoy a reduced average "%load" in revenue service. The adoption of the distance-based approach is an important step toward matching the GEM model to real-would use. However, as standards are finalized, the accelerations and grades of cycles embodied in the GEM execution must represent real life as well. If the grades and acceleration values are not appropriately challenging, the distance-based approach will look more like a time-based approach, because underpowered trucks will be able to follow the trace in the minimum time allowed. This would divorce the market incentives from the environmental incentives and create a false impression of fuel efficiency capability at the expense of economic reality. It is important that the grades and test weights used are realistic and representative. Further, the indication of the ratio (actual / minimum time for cycle completion) is a very beneficial output value.

A driver's habits are known to have a measurable impact on truck fuel efficiency. This is in part due to gear selection that influences the engine operating envelope, and in part due to transient pedal demand (driver PI controller), that may cause an engine to depart from steady-state mode to a greater or lesser degree. The GEM load demand controller and GEM gear selection algorithms can be configured to reflect different driving habits. If the chosen GEM driver yields a better fuel efficiency than would be expected of the national average driver, then GEM will fail to grant auto-shifting technology and certain engine control strategies their full potential contribution to efficiency gain. It is recommended that this issue is at least explored to provide driver sensitivity results to the accompanying document.

The engine model in the new GEM is still a steady-state map. The documentation acknowledges that transient fuel efficiency will differ from steady-state efficiency at the same speed and load in time. A transient adjustment factor (TAF) seems likely for the final version, but the use of a steady-state map with a TAF does not encourage manufacturers to improve transient fuel efficiency if a generic TAF is assigned. This reviewer appreciates that manufacturers are unwilling to reveal strategies that represent a substantial fraction of product value, yet they cannot take advantage of their improvements in the model without this information. Two solutions are possible:

(i) Determine a manufacturer-specific TAF rather than an agency-specified TAF, or
(ii) Determine an alternate fuel efficiency map for transient (e.g. Heavy-Duty FTP) operation, and use that map or both steady state and transient maps for the transient cycle.

In addition, TAF will need to be considered carefully for gasoline and natural gas engines, where enrichment management has an important effect on fuel efficiency. In a similar way, cylinder deactivation strategies may be difficult to characterize for throttled engines, because the deactivation strategy is not well represented by a steady-state map. It is important to have a TAF strategy that acknowledges successes of manufacturers in lowering transient operation disadvantages.

The EPA developers have sought comment on the issue of axle efficiency. It can be dangerous to employ the overall fuel economy computation to compare two approaches to modeling a single component, particularly if that component represents a small loss. In one case, the overall fuel economy differed by 1.67% when a simplified efficiency was compared with a lookup table for rear axle efficiency. This 1.67% represented more than a third of the loss associated with that component. To place this in further perspective, the 1.67% can be compared to the 3-5% contributions of a major component, such as side skirts on a semi-trailer at freeway speeds. Generically, if a component model with higher fidelity is available, in the opinion of this reviewer, it is worth including the detail in GEM, even if the component model is fixed in GEM. Furthermore, the existence of such a model may provide a clearer pathway for entering technology advances by a manufacturer who improves that component in the future.

The tires in GEM are simply characterized by a rolling resistance coefficient and an effective loaded radius. It is known that the coefficient varies with vehicle speed and contact area, while longitudinal slip can change the revolutions per mile by a few percent under driving torque and braking, which could bias results more substantially when grade is present. This could be coded into GEM, but it is probably more appropriate to treat it as a comment, since detailed tire data of this kind are not in the public domain and test methods are not universally defined.

c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO2 over the given driving cycles;

The accompanying explanatory document emphasizes that the input and output structure has not been finalized. A comment, intended as guidance, is that manufacturers will be obliged to use the executable version of GEM a large number of times to cover each order or each truck technology change over the year. This is needed to compute an average value for compliance. The EPA should make every effort to insure that the final version can be interfaced with the manufacturers' software to insure that the process is efficient and reasonably inexpensive, while keeping that version of the model locked to insure compliance.

The .csv output files, viewed in Excel, provide a representation of likely input and output files. These summaries are very useful and appropriate.

d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.

The default values are not particularly important at this stage of development. They are sufficiently representative of recent or current technology to provide reasonable inputs and to assess the ability to predict real-world values. However, this is an appropriate point to acknowledge and discuss the comparison of GEM output with real-world measurements, as described in the supporting material.

The real-world data serve to verify the ability of GEM to model a variety of trucks. These data do not extend to the validation of truck tire rolling resistance or aerodynamic drag value selections because the validation was conducted using roller and powertrain dynamometers, where these values were entered and were the same values used in GEM. Generally GEM matched the measured fuel efficiency values to within 5%, and the deviation may be attributed both to measurement error and to the inherent simplifications in modeling. There are some systematic errors evident in the comparison. For example, the T700 truck efficiency is underpredicted (GEM vs. measured) on the high speed tests and overpredicted on the low speed tests. This trend differed for the T270 and F650 trucks. The refuse truck fuel efficiency was uniformly overpredicted. This leads to the conclusion that GEM may be capable of predicting overall fuel efficiency accurately (at the 5% difference level), but that one should still be cautious of comparing the performance of very different technologies using the GEM tool.

The narrative states that "While it is encouraging that GEM accurately simulates overall vehicle performance in an absolute sense, it is actually more important that GEM is accurate in relative comparisons." This is true in the sense that GEM should encourage the best technology pathways through comparison, but it is nevertheless the single overall predicted efficiency that is of interest to the manufacturer because it predicates compliance. As an example, when the axle ratios were adjusted for a vocational truck from the chosen value of 3.76 to high (4.06) and low (3.46) values, the predicted transient fuel economy values were 5.55, 5.49 and 5.6 respectively. In contrast to this small variation, the fuel economy values for the 65mph operation were 7.14, 6.88 and 7.37 respectively, attributable to the 9% difference in engine speed between the high and low ratios. This reviewer has confidence in these relative values where a variable input is changed. However, a comparison between two vehicles with identical chassis and bodies, but with different engines, transmission types and tire rolling resistance challenges several parts of GEM in a differential sense, and a greater comparative error must be anticipated. One cannot argue that the overall agreement with the measured data verifies each sub-model within GEM.

The use of single variables to represent a more complex reality is discussed elsewhere in this review.

The cycles chosen for evaluating vehicle performance can be changed readily in GEM. Although incorporation of grades represents a substantial advance, the current choice of fixed 55mph and 65mph steady speeds may cause designers to "teach to the test." [The CBD cycle, used in a previous age to quantify transit bus performance, suffered from problems of this kind because all steady state operation was at 20mph.] The output data for the tractor (through engine speed / vehicle speed ratio) show that the highest gear was used for both fixed speeds. Use of a test cycle where speeds varied slowly through the 50 to 70 mph range could avoid pitting real world optima against model optima, and would encourage engine downspeeding strategies that are successful in revenue service where speed limits are not necessarily 55 and 65mph.

3. When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?

The GEM tool as presented to the reviewers provided a workable compromise between accuracy and simplicity. It is evident that GEM may be improved in accuracy by increasing input data, in particular the substitution of data tables for single values. However, these tables would need to be created for each component at substantial expense. Also, it would be better to use real values or tables or strategies from manufacturers, but each of these might require audit and prescribed measurement methods, and in many cases the manufacturer considers them to be proprietary. The present GEM is close to being optimized: clearly development is still taking place.

As a general observation, the engine and transmission receive substantial attention in GEM and in much work on truck efficiency improvement. They seem to be of interest at the single percentage level. However, tire rolling resistance is a major influence for vocational trucks, and drag coefficient controls the dominant loss for freeway tractors. Yet these two components are each represented by a single parameter. Beyond just GEM, a more detailed consideration of these components (e.g. longitudinal slip of tires, rolling resistance during crosswind correction, effects of yaw on drag) would assist in raising modeling accuracy. If that cannot be considered expediently for this version of GEM, it should be considered in the future, or even embedded in the tables so that it can be applied without altering the code.

4. Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).

The .csv output results are sufficiently comprehensive for the user who is not executing the program in MATLAB for research and design purposes. Presumably a report similar to the .csv is anticipated as the executable version output. In fact, to the manufacturer, who is executing this at time of sale within a larger accounting loop, a very succinct output would be sufficient.

5. In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?

Words of caution may help in presenting GEM to the user and to the public. It is important to state that GEM has acceptable accuracy in predicting the fuel efficiency of a specific vehicle under specific circumstances. However, it is equally important to state that if GEM is used to compare two competing, but very different, technology packages, it may not have the fidelity or granularity to evaluate which is better. GEM may not determine the relative difference between the two with high fidelity, and that relative difference will depend on the vehicle vocation or test cycle used.

Although modeling test weights were provided for the example vehicles, there was no quantitative discussion of choice of test weight for GEM. Test weights receive only brief mention in the supporting documentation. It is possible that within vehicle classes, or across regions with different topography, engine size may be selected based on the anticipated load. The distance based strategy shows an appreciation for this issue, but some compensation with test weight for engine size could be considered. Perhaps test weights could be selected so that the time to complete the route remains within reasonable bounds for more lightly powered vehicles, but at least that highly powered vehicles are acknowledged to be appropriate for some occupations, loads or regions. The vocational tractor option in Phase I is not a comprehensive solution.

III. SPECIFIC OBSERVATIONS

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
8	1	Axle lookup table is a better approach
8	2	"Brakes" Addition of the inertia component to axle is curious/ a curious description. This is rather a retarding torque. Perhaps the inertia becomes a force if MATLAB is viewed over time steps. I was confused by this language.
10	2	It would be good to see (as well) the equivalent to Figure 1-3 with the proposed locked shifting strategies in GEM, rather than actual strategies as discussed on p. 10.
16	2	Need to be cautious about claims in modeling changes. Effect of change in Crr is clear, bur GEM may have difficulty with relative accuracy in changing transmission type.
16	2	Note in presenting these agreements that Crr or Cd changes are entered as dynamometer A-B-C coefficients, and these are not real world measurements. Essentially the dynamometer is partially modeling these effects.
17	Table 1-3	And the figure. Note that the 1.8% error represents a 17% error based on the difference, if this figure is intended to show the accuracy of predicting differences rather than absolutes.
18	2	GEM is using automated shifting, essentially, for both MT and AMT, and this will be used (with PI control pedal) for impact assessment. Yet this paragraph brings human drivers to the fore. Philosophically, that the human drivers are the truth and the accuracy of revenue service, more than the model or powertrain cell.
19	Fig 1-9 to 1-13	Are these with default or manufacturer's shift tables?
22	Table 1-4	Little or no shifting occurs in the 55 and 65 cycles. That should be stated.
23	End of page	Text should explain in a little more detail how these powertrain tests may be inserted into GEM

Specific Observations on Electronic Model Entitled, "GEM Tool"		
Input	**Variable**	**Comment or Question**
		No Specific Comments or Observations Provided.

Peer Reviewer # 2

Peer Review Comments on EPA's Heavy-Duty Greenhouse Gas Emission Model (GEM): Phase II and Supporting Documentation

I. GENERAL IMPRESSIONS

This document summarizes the findings of the review of the US EPA's Heavy-Duty Greenhouse Gas Emission Model (Phase 2 GEM) and supporting documentation ("Vehicle Simulation Model"). The tool will serve as the principal support for the second round of Heavy-Duty GHG emissions regulations, which are under development by NHTSA and EPA. The agencies are considering recognizing the efficiency of various vehicle, engine, and transmission technologies and they consider critical to develop methods that assess the expected real world performance of those technologies. The main purpose of this review is to evaluate how well the developed model can serve as a regulatory and compliance tool. The following represent my review of the tool and accompanying report based on my experience in modeling heavy-duty vehicles with full-vehicle simulation tools, as well as from our assessment at the International Council on Clean Transportation (ICCT) of other heavy-duty vehicle regulatory models used around the world.

After reviewing the Matlab/Simulink model and the accompanying report, my general impression is that the "Phase 2 GEM" constitutes a valuable development effort by EPA to develop a rigorous tool that represents the relative efficiency and emissions of vehicles. The new modeling tools' comprehensiveness, quality and amount of data inputs, and modeling structure reflect state-of-the-art modeling techniques and accurately represent relative efficiency differences of vehicles in real-world conditions.

The model architecture is clear and easy to follow and has incorporated some key features that will enhance its overall accuracy with respect to real world performance of technologies, and will allow the model to capture fuel consumption reductions from a broader range of technologies. Overall, the tool offers a rigorous and comprehensive simulation accounting of both engine-specific and full-vehicle effects in a manner that is suitable for the regulatory compliance purposes as indicated. The model will be capable of performing its intended purpose of reflecting technology benefits for compliance purposes of most of the technologies that the agencies are considering.

Some new vehicle modeling features are especially important, namely the ability of the model to incorporate user-defined engine fueling maps and driveline parameters, the development of different transmission options, the enhanced transmission gear-shifting strategy, the inclusion of a distance-based routes with road grade, and the more comprehensive treatment of vocational truck technologies. The accompanying testing effort that was undertaken to validate the model is impressive and thorough, as capturing the effect of combinations of technologies in such close agreement with powertrain and chassis dynamometer testing is a difficult task. The model development demonstrates a thorough development process, and also shows a strong commitment to transparently presenting the data and methodology that were involved.

The comments below provide additional details, as well as some suggestions that could also be considered by the agencies in the final model development.

Although the tool itself offers a suitable modeling platform, the document that describes modeling approach could provide further details in a number of areas. It appears as though the documentation available for this peer review was at an early draft stage. There is an overall lack of detail on key technical features that are new in the model. Interested readers would gain from better descriptions of such features, how they were developed, and perhaps, more quantitative results in several areas. Also, the quality of the report may be enhanced with more consistent use of terminology and a reduction in the number of self-references. Further details regarding areas where such documentation and enhanced information would be helpful are described below.

II. RESPONSE TO CHARGE QUESTIONS

1. Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?

The proposed Phase 2 standards are predicated on the performance of a broader range of technological improvements than Phase 1, including changes to transmissions and better integration of engines and transmissions, so a more comprehensive model is required. The model in its current form will be capable of performing its intended purpose of reflecting technology benefits for compliance purposes of most of the technologies that the agencies are considering.

The model is enhanced in various aspects with respect to its previous Phase 1 version. Fuel maps are one of the most important elements in simulation-based models and the new feature of using actual maps and drivetrain parameters would make the results more realistic, allow the model to capture the effects of matching engine and driveline, and ideally promote right sizing of the engines to application. Different transmission options are included in the model. The shifting behavior is now more realistic since is based on both throttle and speed inputs, and includes the effects of a clutch friction model. Phase 1 GEM shifting strategy was based only on vehicle speed and there was no torque interruption during shifting. Road grade has a major impact on fuel consumption and its addition to the tests cycles would also make the results more realistic. The treatment of vocational technologies, which were limited to the tires in Phase 1, is considerably enhanced. The approach followed by EPA to tackle the diversity of vocational truck applications is appropriate. A few drive cycles are simulated (ARB transient, 55 mph and 65 mph cruise with grade, and a new idle cycle) and weighted differently based on specific application.

EPA's approach involved a good amount of testing and validation. It must be said that most of these validation efforts only covered fuel consumption results from reduced weight, better aerodynamics, and better tires. The validation effort for transmission types and engine-transmission-vehicle interaction was less comprehensive. However, based on the results presented, Phase 2 GEM model would be accurate enough to support regulation and drive technology adoption.

More broadly, I make one final comment on how the overall modeling approach may meet EPA's overall goals for the regulation, related to the public release of the GEM input and output data. The existing and Phase 2 heavy-duty vehicle regulation approach relies on the GEM inputs and outputs to determine compliance. The GEM data are analogous to the light-duty vehicle gram/mile[1], heavy-duty vehicle gram/brake-horsepower[2], and light-duty vehicle mile-per-gallon[3] compliance values. For the heavy-duty use of the GEM in the greenhouse gas emission regulatory program to meet the agency's own standard, the input and output data from GEM would ideally be made publicly available just as the regulatory data for the other regulations for each engine and vehicle. For the public to have confidence in the regulatory program that is built on a mix of engine- and vehicle-model-specific inputs and modeled GEM outputs, the underlying data would be presented in full in downloadable data files (e.g., in Excel) as in other EPA regulations.

References:
[1] EPA http://www.epa.gov/otaq/crttst.htm
[2] EPA http://www.epa.gov/otaq/certdata.htm
[3] EPA http://www.epa.gov/otaq/tcldata.htm, http://www.fueleconomy.gov/feg/download.shtml

2. Please comment on the appropriateness and completeness of the contents of the overall model structure and its individual systems and their component models (i.e., using the MATLAB/Simulink version), if applicable, and considering the following:

- ***a) Elements in each system used to describe different vehicle categories;***
- ***b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;***
- ***c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO2 over the given driving cycles;***
- ***d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.***

Overall the model structure and its systems are appropriate and, in large part, complete. Generally, the performance of each component model and the underlying equations and physical principles are valid throughout (see some finer details below). The input and output structures interact with the model to obtain the expected result in a way that is sound. The following sub-sections comment on specific issues regarding model structure, individual systems, as well as default values, in no particular order of importance.

Fixed payloads

Phase 1 GEM had predefined engines, driveline parameters, and payloads for every category. An issue that may arise when using user-defined engine fueling maps in combination with predefined payloads is that some simulated vehicles, with lower power-to-weight ratios, will show higher deviations from the target speed-distance trace. This affects the simulation results since these underpowered vehicles will take more time to complete the assigned route and will show a lower average speed. This could lead to underpowered vehicles being improperly credited.

Appropriate matching of engine, transmission gear ratios, axle ratios, and tire radius is only going to be promoted if the GEM payloads closely match actual vehicle operation. Right sizing of powertrains to application does not seem to be promoted when payloads are predefined for a particular vehicle category. In order to recognize engine power matching to vehicle road load, payload needs to be a user input rather than a predefined parameter. The regulatory approach and modeling would ideally recognize and promote market diversity and identify potential discrepancies between actual payloads and GEM payloads. There is an existing trend towards smaller engines, but also some applications require larger engines. On the other hand, if the truck manufacturer is allowed to input vehicle-specific payloads, some issues may arise in terms of enforceability (How do the regulatory agencies ensure that the vehicles are operated close to the payload values at which they were certified?), that may also open the door for the manufacturers to report numbers for their own benefit, and adds complexity.

An option could be to adjust the payload on a few pre-defined bins based on certain parameters that are indicative of vehicle road load (e.g. engine displacement, engine power, final drive ratio). Under this option, a performance criterion that captures the trace-following capabilities of the simulated truck (e.g. a set threshold of percent difference between target speed and simulated speed) can be used to force certain engine-vehicle combinations to switch to a lower payload bin if they don't follow the trace according to the specified criterion. Another option would be to impose a CO2 penalty based on the ratio of simulated average speed to target average speed. Ideally, the allowed deviations from the target trace should be minimized for the simulations to be considered valid and allow comparisons between them.

Drop-down technologies

The agencies have identified a list of technologies that provide fuel consumption benefits but are difficult to simulate accurately. They are developing feature-based drop-down menus that make post-simulation adjustments (percent reductions) to the results. It appears that manufacturers have not taken much advantage of the Phase 1 advanced technology structure to earn credits so it is important to try to include most of the technologies in some way. However, drop-down menus inherently assume that all the technology variants within a technology category provide the same fuel consumption benefits. Not all the models and brands of a certain technology feature would provide the same fuel consumption benefits. There is the risk of giving artificial credits to products that perform at a lower level than the value that is selected from the drop- down menu, thus rewarding poor performers. Also, technology products with better than average levels of performance would not get additional credits, which is a disincentive to make investments in the development of such technologies. The default improvement values (percent reductions) developed by the agencies were not shared for this peer review but they are of relevance and need to be determined with care. Currently, the users have no flexibility to enter their own values. Giving the users the flexibility to enter their own values (after testing and with proper documentation) could offer a way to reward good performers.

It seems that applying adjustment factors in terms of percent reductions rather than applying predefined credits in units of go2/ton-mile or gal/ton-mile may punish good performers. Assuming that truck A emits 90 go2/ton-mile and truck B emits 100 gCO2/ton-mile. If a certain technology improvement value is set at 5%, and both trucks use such technology, truck A would get 4.5 gCO2/ton-mile credit and truck B would get 5 gCO2/ton-mile credit. This discrepancy of incentives can exacerbate if the trucks use more than one drop-down technology and the agencies decide that the percent improvements are additive. So it would be good for the agencies to support whether and why percentage-based (versus gCO2/ton-mile based) are most appropriate. Also the agencies might address, in such drop-down menus whether such technology improvements are indeed additive or not.
Another issue with drop-down technologies is that there is the potential for double counting of technology benefits. As an example, an electric coolant pump is listed as a drop-down technology. Depending on the engine mapping process, the resultant engine fuel map may already capture the benefits from that technology. Running a simulation with such a map, and

later improving the results using a drop-down menu will double count the benefits. If EPA could respond to how potential double-counting situations are minimal, that would be helpful.

Driver subsystem

In vehicle simulation modeling, it would seem that the driver ideally would be excluded entirely as a factor that could influence the GEM regulatory compliance results. Using the same driver model for all the vehicles seems to be an appropriate choice. However, additional documentation is needed for this subsystem. There are no details about how the proportional and integral gains of the PI controller have been selected. Are they representative of current drivers? Are they tuned to enhance the trace-following capabilities of the model? The look- ahead feature also lacks documentation. Is it bringing any advantage to the trace-following capabilities of the model? How was the time span value for such feature selected? Ideally EPA would provide some consideration and discussion of such factors to provide greater assurance that no anomalies occur in compliance results from company-to-company technology strategies as well as tested-versus-real-world results for the relative technology benefits.

Transmission subsystem

There are some transmission-related features that are confusing and need to be clarified. The report mentions that the different transmission models: manual (MT), automated manual (AMT), and torque converter automatic (AT) are built of similar components, but each features a unique control algorithm. However, the model seems to use the same "auto shift algorithm" to determine the operating gear for any transmission type. The differences in the control algorithm of the three different transmissions are not clear and need to be provided. Since transmissions are an important new addition for Phase 2 GEM, it is important to let the reader know that the control strategy (e.g. shift points) or the selection of predefined transmission parameters (e.g. efficiencies and inertias at different gears) are not creating any artificial advantage of one technology type over the others. I suggest presenting a comparison of the same simulated truck with different transmission types. It is also important to highlight in the report that the new transmission controller is based on both speed and throttle position, and differs from the Phase 1 transmission controller, which was solely based on vehicle speed. The rule-based approach of the "auto shift algorithm" would ideally be documented.

It would be appropriate for the agencies to acknowledge that Phase 2 GEM simulations can capture some but not all of the benefits of powertrain integration. The simulation would adequately capture engine down speeding since the users have to input specific transmission gear ratios, final drive ratio, and tire radius. However, there are many complexities in the control strategy when it comes to integrating engine and transmission. Integrated engine-transmission powertrain approaches with advanced controls and shifting algorithms that many companies are developing could result in significantly more (or less) benefit than the agencies determine as the Appropriate default emission-reduction effect.

As an example, if two different vehicles have the same driveline parameters (tire radius, final drive ratio, transmission gear ratios, transmission inertias, and transmission efficiencies) and AMT transmissions from different manufacturers, they will obtain the same simulation results in GEM but, due to differing control strategies and other design characteristics, they will show different fuel consumption benefits in reality. It cannot be expected that all the AMT transmissions bring the same fuel consumption benefits. The drop-down menu option won't handle these differences unless there is an option to choose manufacturer-specific transmissions or otherwise input such data.

As a result, there is an opportunity here to leverage the powertrain testing and provide the option for manufacturers to better capture the fuel efficiency gains coming from the control strategies and other complexities that are not adequately captured in GEM. Another advantage of powertrain testing is that the manufacturers would not need to disclose confidential information. The results from powertrain testing can then be implemented as correction factors for the GEM results. Using correction factors, GEM results could be multiplied by a fixed percent improvement obtained by comparing the results of powertrain test and GEM simulations under the same torque-speed trace.[4] The default benefits for transmission improvements would ideally be set to be appropriately conservative (i.e., lowest expected value based on various industry results) in GEM. The drop-down menu could still then be offered as a default, for the manufacturers that decide not to use the powertrain testing. Then, for the powertrain option, companies would ideally be provided clear testing procedures and guidance to demonstrate the emission-reduction impact of their advanced powertrain approaches with physical vehicle testing in simulated real-world conditions.

<u>Engine fueling maps</u>

The inclusion of manufacturer-specific engine maps is a critical feature to reflect company differences and detailed engine-specific characteristics that reflect real-world fuel consumption and emissions. This is an important addition to GEM, but there is lack of documentation of the engine mapping procedure. I imagine that a fairly prescriptive procedure (including number of points, preconditioning and warming procedures, fuel properties, etc.) is described somewhere else in the larger regulatory development document but this chapter would ideally include a brief description of the procedure so the reader knows which engine accessories are included or excluded during the engine mapping procedure.

It is noted that there are many advanced features that may affect fueling but are not captured by using a steady-state fuel map. Manufacturers are going away from traditional map-based strategies and are going towards model-based controls. Diverse thermal management strategies are utilized, and some engines use dual torque curves. Have the agencies considered how to handle these technologies? This could have important implications for how tested steady-state engine maps, and GEM modeling, and real-world emissions characteristics could differ. As a result, we recommend that the agencies discuss such industry approaches in the rulemaking and investigate ways to ensure that tested results are aligned with real-world engine and vehicle operation the results in fuel consumption and emissions.

The approach used to quantify the transient correction factor (run GEM with the engine map, then use the torque-speed points in the engine dynamometer and compare measured versus simulated results) is appropriate. Ideally the transient correction factor may be obtained for each individual engine. However, since there is a need for selection of a vehicle in GEM in order to get the torque-speed trace. It would become a hard task for the agencies to try and run a transient correction factor for each vehicle-engine configuration. For practicality, I recommend provisionally using a single correction factor and maintaining the option to refine it over the years with additional testing.

<u>Modeling of idle cycle</u>

The idle cycle modeling would gain from increased documentation. Using a gCO2/mile value for an idle cycle at first seems counterintuitive (i.e., there are no miles traveled) so a complete description of the calculation method would clarify. It would be desirable to present some validation results for the idle cycle modeled in GEM compared to experimental results. Some of the engine auxiliaries may not be enabled while doing the test, and the map could be underestimating actual idle speed fueling rates. There are also engine thermal management strategies that are used to keep appropriate after treatment system temperatures. These strategies vary from manufacturer to manufacturer and could increase idle fueling substantially.

The "trace following" issue discussed above also has implications in the calculation of idle cycle g/mile value. For this calculation the fuel rate in units of grams per hour [g/h] is converted to units of grams per mile [g/mile] using the weighted average speed over the three non-idle cycles. The target speed is used for this calculation and not the actual simulated speed, which may penalize smaller engines. I suggest EPA to consider if this issue might be significant.

Trailers

Although there is a parameter in GEM for trailer tires' rolling resistance, it is not clear how trailer aerodynamics is going to be modeled in GEM. Trailer aerodynamics can bring about two-thirds of tractor-trailer aerodynamic benefits, so this is a critical area that requires documentation and specification of the procedures for the vetting, binning, and including the input data. My understanding is that the Coda input parameter is for the tractor only (mid-roof and low roof tractors are tested in its bobtail configuration), or for the tractor using a "reference" 53-ft dry van trailer (for high-roof tractors coast-down test). Trailer aerodynamic devices can reduce the overall tractor-trailer combination aerodynamic drag and ideally the Coda used in simulation should represent the combination. It seems that there is no current provision to include the effect of trailer aerodynamics as an input in GEM. The report needs to clarify how the GEM model is handling trailer parameters (including aerodynamics, tires rolling resistance, and weight reduction) and if the model is going to use a predefined "reference" trailer for all the tractors. Ideally agencies would give credit to tractor-trailer integrated designs although it would be difficult for the agencies to ensure in-use compliance of matching of tractors and trailers.

Accessories

There are opportunities for fuel savings from mechanical accessories and electric accessories but the agencies decided to keep with the Phase 1 approach of having pre-defined and not customizable power from accessories. If these parameters are assigned default values, there are no incentives to implement new technologies that could have greater impact. Allowing accessories power consumption to be user-defined inputs can be used to promote developments in technologies that reduce the power requirements of accessories such as the alternator, air-conditioning compressor, power steering pump, or cooling fan. There are other opportunities for engine accessories such as oil, coolant, and fuel pumps, but is not clear at this point if all those savings are going to be captured by the engine mapping process.

References:

[4] See Sharpe, Delgado, Muncrief (2015) Comparative assessment of heavy-duty vehicle regulatory design options for U.S. greenhouse gas and efficiency regulation. http://www.theicct.org/us-phase2-hdv- regulation-design-options

3. When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?

The chosen methods and execution of the model shows strong engineering judgment throughout. A good indication of proper execution is the overall good agreement between the Phase 2 GEM simulations and testing data obtained with chassis and power train dynamometers. The errors shown are well within +/-5%, which is within the test-to-test variability of chassis dynamometer testing. Execution at this level of fidelity meets our own criteria that we have utilized to validate tractor-trailer simulation results.[5] the validation results show that the balance between model accuracy and simplicity is adequate. As a result, the program would be effective to model a diverse set of technology changes and be used in regulatory applications.

References:

[5] See Delgado and Lutsey (2015). Advanced tractor-trailer efficiency technology potential in the 2020-2030 timeframe http://www.theicct.org/us-tractor-trailer-efficiency-technology

4. Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).

The data reports did not appear to be fully complete, but the accuracy of the output/results appears to meet reasonable expectations. The input and output structure of GEM was not finalized when released for peer review, however some samples of the output files were provided to give the reviewer a flavor of the potential structure. In my opinion, for completeness, the output file needs to include results for each different cycle and not only for the weighted aggregation of cycles. Some metrics can be added to the output file to facilitate troubleshooting and give the user a better perspective. As mentioned before, actual simulated speeds and a measure of deviation from the speed-distance trace would ideally also be provided for transparency of the results. Based on the validation results, accuracy with respect to measured data was provided and seems to be within 5%, which is acceptable output accuracy based on comparable modeling as well as real-world testing.

5. In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?

Phase 2 GEM could generate two different output reports. One that only includes the most relevant information on an aggregated format and is used only for compliance purposes, and a second one, that is very detailed and includes results disaggregated by cycle and other relevant information that may help the users to troubleshoot their results, learn the inner workings of the model and potentially suggests enhancements to it. I suggest including a summary of the energy audit in the output. Also, provide the average engine efficiency over the cycle for the different test cycles, as well as the ratio of average engine efficiency to maximum engine efficiency, which is an indication of how well the transmission parameters are matched to keep the engine operating near its peak efficiency range.

The output file provides some basic "sanity checks" such as number of shifts, ratio of number of shifts to number of gears in the transmission, distance traveled, and ratio of actual time to target time. Please also provide ranges of valid or acceptable values for these parameters so the user can be aware of any potential issues with the simulation.

A further step that could allow the tool to be much more useful would be to allow users to input their own cycles as is currently done with VECTO[6] (Vehicle Energy Consumption calculation Tool) model in Europe. The VECTO tool has a "declaration mode" for compliance, and an "engineering mode" which offers the ability to edit inputs and allow users to explore what the tool can do. This would be critical for transparency and follow the best practice as seen in the Europe situation. It would also be highly useful for individuals in the heavy-duty vehicle supply chain to explore the variation of the results with respect to real-world duty cycle factors. Especially considering the very diverse use of heavy-duty vehicles in local, regional, and long-distance conditions, this capability would allow dealers and fleet managers to gauge how fuel consumptions for particular relevant driving patterns differs from the cycle. This would help ensure the technologies that are more suited to particular duty cycles are being selected in the market place, and it would also help overcome the prevailing market barrier, whereby knowledge, data, and confidence on truck efficiency has been limited.[7]

References:
[6] See Luz et al (2014)
http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/final_report_co2_hdv_en.pdf
[7] See Roeth et al (2015) http://www.theicct.org/hdv-technology-market-barriers-north-america

III. SPECIFIC OBSERVATIONS

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
2	2	The list of key technical features may include the fact that the new model uses distance-based cycles instead of time-based cycles, and the fact that test cycles now include road grade.
2	2	The claim "more stable engine idle speed controller" is not discussed in the text. Some metric or quantification of what is meant by "more stable" needs to be provided.
2	3	Regarding "substantial effort has been put forth to accurately track and audit power flows through the model to ensure conservation of energy" The report lack details about the energy audit. Was the energy audit developed just for internal quality control or is it going to be provided to the end users in an output file?
3	1	Regarding "the road gradient has been modified to accept a road grade that varies as a function of distance traveled" Please introduce the concept of distance-based versus any pros/cons of the new method and why did you change the approach.
3	2	Driver subsystem. This section (1.2.2.2) is not clear to the reader and, in my opinion, needs rewriting. There are various confusing statements such as "the feed forward calculations using drive cycle accelerations and vehicle mass have been removed". The section also mentions (page 4, paragraph 1) that a ratio of speeds (which is non-dimensional) is integrated to produce the current cycle position (which has units of distance), which is dimensionally incorrect. I recommend showing the equations to avoid confusing the reader.

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
		Regarding the statement "the addition of distance compensation allows all simulated vehicles to complete an equivalent trip such as traveling from point A to point B" Does that mean that without distance compensation the vehicles would not complete the trip?
3	2	How were the proportional and integral constants of the PI controller estimated? Is the same driver subsystem used independently of transmission choice? How was the look-ahead feed-forward control implemented?
4	2	Consider removing the mention to the "variant power train architecture" since it is not mentioned anywhere else in the report.
5	1	Please clarify that the engine map is not a pre-determined parameter as in Phase 1 GEM, but a user-defined input.
5	3	For consistency with previous section, please show the proposed constant power loss magnitude of electric subsystem.
5	4	Please change "four different variants" for "three different variants" (MT, AMT, AT).
11		There is an apparent incongruence in Page 5, paragraph 4, which mentions that each transmission "features a unique control algorithm matching behaviors observed during vehicle testing" however, in Page 5, paragraph 5 it is mentioned that "all of the transmission models use an auto shift algorithm to determine the operating gear over the cycle". Are the auto shift algorithm parameters changed based on transmission type? Is there really a unique control algorithm for each transmission type?
5	5	The "auto shifting optimizer" needs proper documentation. How does it work?
6	1	The clutch model is a key new addition and lacks proper documentation. Please support claims such as "realistic actuation durations and more accurate physics of torque conservation and lockup behavior" with data.
6	2	Please clarify what you mean by "This layout is more similar to a manual transmission, but the application for a planetary gearbox is a reasonable approximation as this type of gearbox can utilize a variety of topologies" is confusing to me.
8	2	The statement "The brake model also adds a rotational inertia component to the axle" is misleading since the inertia of brakes is set to zero in GEM.
9	2	Please provide a table with a complete list of pre-defined and user-defined parameters. There is no need for specific values, just the list of parameters.
12	1	Description of test condition number 6 reads, "Run a new set of road load coefficients to represent a vehicle configuration optimized for fuel efficiency for each vehicle that was tested."

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
		To be consistent with the other test conditions described please quantify the reductions in rolling resistance, aerodynamic drag, and mass for this particular "optimized package" case.
13	Figure 1-3 to 1-6	In the legend, it is not clear if the 55mph and 65 mph tests contain grade or not. Also, the "utility" cycle is not described in the text.
15	Figure 1-6	Although is mentioned in the text, it seems that the refuse truck was not tested under the refuse cycle. Also, it seems that it was not tested under different test conditions as the remaining vehicles. Any reason for this? Please explain.
16	1	Change "numerically" for "numerical."
18	2	The statement "In some cases, it is hard to quantify which method, vehicle simulation or chassis dynamometer test, is more accurate" is very misleading. The chassis dynamometer test although imperfect, is a measurement and it was treated as a "true" value in the validation process (Figures 1-3, 1-5, and 1-6). Accuracy can only be measured in reference to a true value. The chassis dynamometer test was selected as such and the model cannot hope to have better accuracy than the test.
18	3	In the statement "GEM is capable of capturing the impact on the total vehicle CO_2 emissions and fuel consumption due to any technology improvement" the word "any" is misleading since the validation effort was only done over aerodynamic, rolling resistance and mass parameters. Moreover, there is certainly a set of technologies that GEM is incapable of model.
17	Table 1-3	Correct the numbers on the "Delta" column. Due to rounding it is not evident that the column represents the difference between the two previous columns. For example in the fourth row we have 3.9% - 4.9% = -0.9%. In the same Table, please calculate the relative error (consistent with Figure 1-8). Is this relative error more relevant than the "delta"? What is the maximum acceptable relative error?
22		Please add a table that summarizes the technologies captured by the simulation and the technologies that are not captured but are accounted for via drop-down menus. A third (optional) column may include technologies that currently are not either simulated, nor recognized by drop-down menus but potentially may be included in future regulations.
22	Section 1.4.1.1	Regarding "As described in Chapter 1.2.2, one of the major changes in the HD Phase 2 version of GEM is to allow manufacturers to enter their transmission gear number versus gear ratio" Chapter 1.2.2 does not mention that fact. Please check throughout the report to avoid issues with these self-references.

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
23	1	Regarding the statement "Manufacturers also have an option to select the type of transmission, which is either manual or automatic" It is not clear if transmission type is a required input or an optional input. Also, the user should have three options (AT, MT, and AMT), not just two.
23	Table 1-4	Table heading should mention that the results are from simulations in GEM, not measurements. Also, it is not clear if the 55mph and 65mph cruise contain grade.
23	4	The report mentions that due to lack of data, DCT, DCT with TC and Allison TC-10 AT transmissions were not validated. That assertion implies that MT, AMT and AT were validated. Since transmission technologies were not tested at the same level of detail as road load reduction technologies, it is important to acknowledge the different level of validation between transmissions and road-load reduction technologies.
23	Last Paragraph	Regarding DCT and other transmission types not included in the model, the report says, "The manufacturers still have the options to use powertrain dyno tests to quantify the benefits of these or any other special transmissions". It is not clear if the results of the power train tests are going to be used to correct the GEM simulation results or are going to replace the GEM simulation results altogether. Please clarify.
24	1	Regarding OEM overriding the axle efficiency input, "the inputs would be determined by using the prescribed test procedure" It is not clear which test procedure is the report referring to. Please add a reference to such procedure.
24	Last Paragraph	Rolling resistance coefficients are usually expressed in units of kilograms per metric ton (1 t = 1,000 kg). The units used (kg/ton) may imply short ton (1 ton = 2,000 lbs.). Please correct and be consistent throughout the document.
25	1	The "Regional", "Multi-purpose", and "Urban" composite duty cycles are not described in the document.
25	3	Please support your statement, "We concluded that for the 55 mph and 65 mph duty cycles, GEM's interpolation of steady-state data tables was sufficiently accurate versus the measured results" What was the observed accuracy of using steady-state maps for the 55 and 65mph cruise cycles? How much accuracy is sufficient?
25	3	The 55mph cruise is named "urban highway with road grade", the 65mph cruise is named "rural highway with road grade, and the ARB transient cycle is named "urban local". Please try to use consistent names throughout. Also, since the cruise cycles in Phase 1 were time-based and did not include road grade, the Phase 2 cruise routes (distance-based with grade) are not equivalent to them and using the same name is misleading. I think a distinction can be made by using the term "route" for the

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
		distance-based tests and "cycle" for the time-based, or simply name them "55mph cruise with grade" and "65mph cruise with grade".
29-30	Table 1-6 & 1-7	Automatic transmissions have the same efficiency for all gears (98%), and such efficiency is equivalent to that of manual and automated manual transmissions in direct drive. Was this advantage observed during testing? If possible, please document with measured data showing the benefits of AT over MT in terms of gearbox efficiency.

Specific Observations on Electronic Model Entitled, "GEM Tool"		
Input	**Variable**	**Comment or Question**
		File: "GEM_run_postproc.m" Lines: 104 to 108. Potential issue: It seems to me that the equation is not dimensionally correct (I might be wrong). Additive terms should have the same units and the equation seems to be adding gCO2/h terms with gCO2/mile terms. Please check for missing terms and/or appropriate use of parenthesis.
		File: "GEM_run_postproc.m" Line: 101. The calculation performed for case 4 is identical to the calculation performed for case 3, making it redundant. Please eliminate case 4 (neutral idle with start/stop), or correct the equation to account for a 90% reduction in neutral idle emissions (not drive idle emissions).
	"vehicle.chassis.frontal _area_m2"	The name is misleading. Please rename to "drag area". Drag area is Coda, aerodynamic drag coefficient is Cd and frontal area is A.
		File: "load_GEM_params.m" Lines: 76 to 85. These equations set weight reduction penalties for spark-ignited CNG (525 lbs.), compression-ignited CNG (900 lbs.), and compression-ignited LNG (600 lbs.). Please set a weight reduction penalty for the missing case: spark-ignited LNG.
		File: "load_GEM_params.m" Line: 94. I am confused about the variable "vehicle.chassis.mass_dynamic_kg" as defined here is a constant. However, during the simulation (variable: datalog.vehicle.dynamic_mass_kg) the equivalent mass of the rotational components vary depending on the active gear.
		File: "load_GEM_params.m" Lines: 117 and 143. It is not clear what exactly the variables "transmission.autoshift.cost_map" and transmission.autoshift.required_cost_benefit_ratio" represent, and how are they used in the model. Other features such as "restrict skip shifts", restrict shift

Specific Observations on Electronic Model Entitled, "GEM Tool"		
Input	**Variable**	**Comment or Question**
		parity", "disable coast saving downshifts" are not well documented in the .m files or in the report.
		File: "load_GEM_params.m" Line: 131. The calculation of "Transmission.gear.inertia_kgm2" involves a multiplication by 0. Therefore it would produce an array of zeroes. Also, assuming that the value of 0 is changed to a finite constant, it seems that the model is assuming the same inertia value for all the different gears. Is that simplification accurate?
		File: "load_GEM_params.m" Line: 134. The calculation of "transmission.gear.spin_loss_torque_Nm" involves a division by a factor of 3.73 for all the transmissions that are not C78_AMT. I am wondering what that factor represents. Also, if that factor is still valid for a potential C78_MT transmission.
		Energy Audit. Net system kinetic energy change is 0 kJ, which is the result of the test cycle starting and ending at 0 mph speed. The test cycle seems to start and end at the same altitude (symmetric grade profile traveled at constant speed), so one can expect the net system potential energy change to be 0kJ as well. Since both kinetic and potential energy are conservative and not dissipative forms of energy, I was confused about the energy audit accounting for energy "consumed" by gradient at about 17% of the losses for a tractor-trailer. Checking the equations, it seems that the energy audit is performed only for positive tractive loads. If that is the case I am confused about the energy consumed by the brakes at about 7% of the losses for a tractor-trailer. They should be really low if one is only considering positive tractive loads. The brakes are mostly applied for negative tractive loads (e.g. driving downhill). Am I missing something here?
		Why the weighted average speed (weighted_avg_speed_mph) used in post processing (file: "GEM_run_postproc.m") is based on the target speed-distance trace and not in the actual simulated speed-distance trace? This decision has implications for underpowered vehicles that deviate substantially from the target trace since their actual average speed may differ substantially from the target speed. This also has implications for the calculation of idle fuel rates for vocational vehicles since the conversion factor from idle fuel rate in [kg/h] to [kg/mile] is the weighted average speed.

Peer Reviewer # 3

Peer Review Comments on EPA's Heavy-Duty Greenhouse Gas Emission Model (GEM): Phase II and Supporting Documentation

I. GENERAL IMPRESSIONS

The EPA Heavy-Duty Greenhouse Gas Emission Model (GEM) Phase 2 documentation accurately represents the structure, format, logic and algorithmic description of the model as presented. The supporting documentation is for the most part, clear and self-explanatory. The results produced by the GEM model appear to be sound, although each set of results is presented as integrated fuel efficiency and carbon dioxide emissions results. As such the results present a single-valued, integrated snap-shot of the model prediction, and the time-based instantaneous fuel efficiency and carbon dioxide emissions predictions are not available for review. The overall dynamic performance of the model prediction is thus difficult to judge in the greater context of what is usually fully transient vehicle operation. Furthermore, in the version reviewed, the ability to vary input parameters and vehicle and drivetrain attributes is limited to modifying input files and not through a graphical user interface as described in the review instructions.

II. RESPONSE TO CHARGE QUESTIONS

1. Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?

The model appears to meet the stated purpose for which it was intended, which is the prediction of integrated cycle-based vehicle fuel efficiency and carbon dioxide emissions for vehicles with preselected physical and drivetrain attributes. While this was the subject of some detailed explanation in the model documentation, the assumption of quasi-steady engine fueling and its extension to fully transient engine operation is not without complexity in the assessment of its validity. A further, acknowledged inadequacy of the model in its current form is the limited ability of the user to modify specific vehicle attributes, and component values and efficiencies.

2. Please comment on the appropriateness and completeness of the contents of the overall model structure and its individual systems and their component models (i.e., using the MATLAB/Simulink version), if applicable, and considering the following:

a) Elements in each system used to describe different vehicle categories;

The elements in each of the systems (engine, transmission, axle, vehicle attributes etc.) seem appropriate and complete. The specific selection of the engines and transmissions chosen will cover a large portion of the current heavy-duty vehicle fleet, although of course any specific, single selection of powertrain hardware or powertrain hardware attributes necessarily limits the range of vehicles that can be simulated with that same selection.

b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;

One concern with the structure and form of the model is that a steady-state engine fueling map is used in each case to simulate transient engine operation and hence dynamic vehicle operation. This is in addition to the simulation of operation under nominally steady vehicle speeds or cruise operation. In the case of nominally steady operation, the use of a steady-state fueling map is well-justified, but the quasi-steady assumption required to allow the extension of the use of such a map to transient operation requires additional justification. Heavy duty compression ignition engines have high rotational inertias (due to the relatively high mass components required to survive the high combustion pressures), high mechanical friction (due to high effective compression ratios) and relatively slow air and exhaust transfer processes (due to the excess air flowrates accompanying their lean, un-throttled operation). In addition they have relatively high thermal mass due to their large physical mass required to withstand the stresses and strains resulting from high combustion pressures. All of these features conspire to result in deleterious combustion effects under highly transient engine operation. In most cases the end effect of these phenomena is to reduce the engine brake thermal efficiency under transient modes, beyond that which would be expected under steady or quasi-steady fueling operation. In most cases the additional fuel that is required to undertake a specific engine transient torque trajectory, beyond that estimated using a quasi-steady fueling assumption, would typically be less than 10% of the total integrated fueling, but in most cases the effect on integrated fuel efficiency over transient duty cycles is non-negligible.

In general, incorporating an additional component into the full accounting of the vehicle load by over-accounting for the actual total rotational inertia (in the form of an effective or "added" mass or inertia) of the drivetrain and driveline system does allow for the quasi-steady assumption to hold. However in general a quasi-steady, forward-looking simulation such as is used in this model, tends to under-predict the actual vehicle energy usage under transient duty cycle operation. I notice that this issue is addressed in Chapter 1.4.1.8 Transient Adjustment Factor, but the designation of a single correction factor for a specific engine or powertrain configuration is likely to be unsuitable in some cases, and has the potential to cause prediction inconsistencies. Note further that the required correction factor might not be uniquely engine-specific, but might vary for the same engine in different vehicle and powertrain configurations.

c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO2 over the given driving cycles;

A further concern that is not discussed in the documentation is whether any model fitting parameters were employed to obtain the fits observed, between the GEM-derived fuel efficiency and CO2 emissions values and the dynamometer-measured results. In other words, beyond the parameters described and the accompanying constants used in the dynamic force and energy equations, were any other fitting techniques (or fitting parameters) used to obtain the observed correlations between the simulated cycle-averaged results and the SwRi chassis dynamometer results? Presumably there were dynamometer parameters and coefficients fitted using vehicle coast-down data (and dynamometer operational parameters), but beyond these, are there any other fitting parameters used to obtain the correlations shown? Discrepancies between simulated and measured results of less than 2-3% are probably not significant, except in the presence of a consistent bias between the measured and predicted, for any one vehicle, cycle or technology considered.

d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.

The default values as defined in the "Vehicle Simulation Model" are reasonable and currently fall within the ranges of expected vehicle values. It is not clear however under what circumstances the user will be able or allowed to make modifications in the final model implementation. For instance, it is conceivable that the interplay between future auxiliary mechanical or electrical loads on an engine might be significantly modified through conversion of mechanical auxiliaries to electrical or electronic devices. In that case, that will shift the relative balance in those loads. Moreover it is not clear that engine cooling fan loads have been adequately accounted for in the model, as these are typically not considered in the engine dynamometer testing from which engine fueling maps are normally derived. This exclusion alone can modify observed fueling rates by 10% or more under specific engine operating conditions.

Other default values including transmission gear ratios, transmission efficiencies, axle efficiencies, tire rolling resistance, and vehicle aerodynamic drag product seem reasonable.

3. When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?

This issue is difficult to address through the level of observation afforded to the reviewer at this stage of development of the model. It is not obvious that the program execution is optimized, but the results, computational time and outputs displayed indicate that the chosen methodologies are suitable for this purpose.

4. Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).

The model outputs and results seem clear, complete and accurate. One caveat with interpreting or using the freight efficiency or load efficiency-based results lies in the use, further interpretation or extension of these results. Users might be tempted to "scale" the load-based results in an inappropriate fashion – for example, if the returned result for the computed carbon dioxide emissions is 100 gCO2ptm (grams CO2 per ton-mile) for say a 30 ton vehicle over a specific cycle, there might be the temptation on the part of users to employ that same numerical result to predict the CO2 emissions for the same vehicle loaded to 40 tons over the same cycle. However this assumption is not correct, as the vehicle fuel consumption is a function not just of load or weight-related terms (rolling resistance, grade, acceleration etc.) but also terms that are invariant with load or weight (such as aerodynamic drag), and this is not reflected in an emissions per ton-mile result.

5. In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?

The version reviewed here does not include the graphical user interface (with "pull-down menus") described in the instructions. The ability to modify input parameters and vehicle attributes will improve the user experience, while obviously presumably not impacting the model outputs.

Due care and attention should be paid to the number of significant digits presented in the output results. For example, in the results presented from a single specific simulation (shown below):

```
>> GEM_Phase2_Idle_55_65_CARB_HHDDT_Transient
 Distance      = 32.414 mi
  Fuel Consumption  = 5.4059 gallons
  Fuel Consumption  = 17184.1217 grams
  Fuel Economy    = 5.996 mpg
  Fuel Consumption  = 530.140 g/mile
  CO2 Emission    = 1697.77 g/mile
```

The number of significant digits in the model simulation outputs presented above (some of which are directly related through derivation or calculation) varies from 4 to 9. This does not meet recommended practices in the presentation of results and data. Moreover, industry experience in the measurement of real-world fuel efficiency during over the road truck testing dictates that measured fuel consumption variations of less than 1-2% should not be considered significant or compelling, and this level of variation could correspond to variations in the 2nd or 3rd significant figures in fuel consumption in most cases.

III. SPECIFIC OBSERVATIONS

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
1		Use "dynamometer" and not "dyno"
Et seq.		Use "Phase 2" and not "Phase II"
5	1.2.2.3.1	Use "watts" or "W" and not "Watts"
5	1.2.2.3.1	"it may o make use" requires clarification
7	1.2.2.3.3.7	"With the new gear engaged the clutch is reengaged and the engine is again allowed to operate at full load." This statement presupposes that the transmission was shifting under full engine load, which is not necessarily the case for high power engines under benign operating cycles.
7	1.2.2.3.4	"This includes drive shafts as well as driven and passive axles, consisting of a differential, brakes and tires." Passive axles will not ordinarily include a differential, only driven axles will.
8	1.2.2.4	"The vehicle system consists of the chassis, its mass and forces associated with aerodynamic drag and changes in road grade". Why "changes in road grade"? Any constant road grade (other than zero) will have an effect on the apparent vehicle load, and not just changes in grade.
9	1.2.2.4	"computes acceleration [not accelerations] from the input force and equivalent mass which is integrated to generate vehicle speed and distance traveled"
9	1.2.3.2	Use "Matlab" or "MATLAB" and not both.
10	1.3	"Validations use all actual vehicle variables conducted at Chassis dyno cell," needs editing.
11		Ref. 3 is not the SwRI report as stated. It is an ASME Technical Paper.

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
12		A +-15% variation in aerodynamic drag, for example, is unlikely to span the full range of expected values in the future for HD vehicles. Presumably aerodynamic modifications to Class 8 vehicles may result in significantly lower drag coefficients, or drag products (CdA)
13	1.3.2	For the Class 8 T700 tests, at high fuel efficiency, the GEM model appears to consistently under-predict the actual measured vehicle fuel economy. This consistent offset is of concern. The reverse is observed for the Class 6 truck tests.
20	Fig 1-11	Caption is incorrect.
21	Fig 1-13	Vertical axis incorrect unit designation.
22		Do not use the term "aero drag". It should be "aerodynamic drag".
22		"tire radius" should be "tire rolling radius" or 'effective radius'.
23		"Lack of testing data for other types of transmission, GEM would not be able to be validated in time against those three cases" requires editing.

Specific Observations on Electronic Model Entitled, "GEM Tool"		
Input	**Variable**	**Comment or Question**
		-- Audit data for GEM_Phase2_Idle_55_65_CARB_HHDDT_Transient drive cycle --
	Aerodynamic drag	"Energy Consumed by Cd" should refer to "CdA" and not "Cd" alone.
	Engine Accessories	Engine Accessories = 846.16 kJ 0.23%
		It seems as though engine accessory loads are under-accounted for in this implementation of the model – a 0.23% loss for a full transient cycle seems inappropriately low.
		Usable System Energy Provided = 373988.49 kJ Engine Energy = 309402.35 kJ Engine Efficiency = 42.08 %
		This integrated "engine efficiency" is high for the average efficiency expected across a fully transient cycle – does this refer to the peak engine efficiency encountered?

Peer Reviewer # 4

Peer Review Comments on EPA's Heavy-Duty Greenhouse Gas Emission Model (GEM): Phase II and Supporting Documentation

I. GENERAL IMPRESSIONS

Accuracy of information:

The document provided, "Vehicle Simulation Model" provides a good background on GEM-II, its differences from GEM-I, and the Phase I certification process. Section 1.2, "Model Code Description" describes the model components and sub-components, in adequate detail for the user to understand the depth and breadth of GEM-II. No underlying equations are provided. The section on Model validation is an important section for GEM-II. The extent of the validation and the comparisons with dynamometer testing is impressive. This gives the reader additional confidence in the results produced by GEM-II. The validation process is well documented, concluding with the graph that summarizes all the 130 vehicle validations performed. The validation also includes graphs of component performance (engine speed, engine fuel rate, and transmission gear number) as a function of time

The document does not explain the variable target.veh_sytyle. The structure format used for the user input data is useful in collecting all user-provided data.

A final conclusions section is missing in the document provided.

II. RESPONSE TO CHARGE QUESTIONS

1. Please comment on EPA's overall approach to the stated purpose of the model (meet agencies' compliance requirements) and whether the particular attributes found in the resulting model embodies that purpose. Were there critical results or issues that were not discussed or addressed by the GEM tool or its component sections?

EPA's overall approach to meet the agency's compliance requirements consists of making a validated simulation model (GEM –II) available to OEMs so that they can check the compliance of their vehicles against the agency's guidelines. The extensive validation of GEM – II against dynamometer testing of the actual vehicle shows a good correlation between simulation and hardware to within ±5%. Most validations are well within ±3%. This provides the user with a high level of confidence that the physics has been correctly implemented and there are no unresolved "bugs" in GEM-II.

Further, an additional level of confidence is achieved, with select validation from four representative vehicle classes, namely: Class 8 Kenworth T700 truck, the Class 6 Ford F650 tow truck, the Class 6 box truck, and the New Flyer Refuse truck. There is a very good correlation between GEM-II predicted engine speeds and transmission gear shifting versus the same on the actual vehicle.

Recommendation: It is recommended that representative vehicles from each of the classes be modeled in GEM-II and validation results presented similar to 1.3.1 of the GEM-II Manual. It is the understanding of the reviewer, based on the provided manual that the following trucks were tested on a vehicle chassis: Class 6 Kenworth T270, Class 6 Ford F650, Class 8 Kenworth T700, Class 8 Cascadia Line Haul truck, and Class 8 New Flyer refuse truck.

<u>Issues/Results that were not addressed by GEM-II:</u>

During this review, the following unaddressed issues were identified for GEM-II:

- GEM-II includes several PID controllers within its overall structure. For example, the engine idle speed controller of the engine is implemented as a PID with three gains. The unaddressed issue in this regard is stability feedback to the user caused by unrealistic hunting for the idle speed. What safe-guards are in place within GEM to inform the user of clutch chattering since GEM does not model second order inertial effects caused during clutch engagement.
- It is possible for the vehicle not to meet the driving cycle as a result of excessive grade or weight or other issues with the transmission/engine. The unaddressed issue in this regard is a feedback alert to the user during the time instances when the vehicle is significantly slowed down and does not meet the desired driving cycle. The output file does not alert the user on the number of time instances when vehicle tracking was compromised.
- GEM-II does not address thermal characteristics of the engine cooling system or the heat rejection of the transmission fluids. These thermal issues affect the operational duty-cycle of the engine fan, which will affect the fuel economy. At present, GEM-II models the parasitic loads as a constant average number.
  Recommendation: Allow the user the ability to introduce an engine load dependent mechanical accessory curve which is more realistic than a constant average number. A simple heat model may be used to capture the effect of thermal characteristics of the multiple radiators in a typical MD and HD engine.
- Although GEM-II does not model tire slip/lockup during a hard deceleration, the effect of ignoring this on fuel economy is negligible.
- The validation results included kinematic comparisons (speeds, gear number) between GEM-II and the actual vehicle on a chassis dynamometer. While, the kinematic comparisons look very favorable, the dynamic comparisons (engine load and engine fueling) are missing in the results section of GEM-II.
- The transmission shift strategy can affect fuel economy and emissions. GEM-II allows the user to preselect different transmission types (manual, automatic or automated-manual). However, it was not clear how to modify the GEM-II default shift strategy with an OEM proprietary shift strategy.
- Although GEM-II results have been extensively validated against dynamometer test data in a controlled lab environment, it is unclear how well GEM-II will compare against real world road testing, especially with temperature fluctuations. For example, the lack of a thermal model in the engine model may cause GEM-II results to deviate from on-the-road test data, where the engine fan is cycled on and off based on thermal loads on the engine. Each time, the engine fan turns on, fuel economy is affected.

2. Please comment on the appropriateness and completeness of the contents of the overall model structure and its individual systems and their component models (i.e., using the MATLAB/Simulink version), if applicable, and considering the following:

The three main powertrain components that can affect fuel economy and greenhouse gas emissions in a vehicle are: engine fuel map, transmission type and efficiency map, and vehicle aerodynamic improvements (including tire rolling friction improvements and weight reduction technologies). In this regard, GEM-II addresses all the aforementioned components by providing steady state maps for each powertrain component, which an informed user can change to represent specific technology improvements. GEM-II comes with certain standard transmission models, namely: manual, automatic, and automated manual transmissions. The user would select the appropriate transmission and GEM-II would automatically select the user-specified transmission.

Recommendation: It is recommended that additional instructions are provided if the user wants to change the engine map. Ideally, this would be done from a user specified spreadsheet in a GEM-II compatible format, since the user may not be fluent in Matlab. In this regard, a clear explanation of all the variables used in GEM-II would also help significantly. For example, it was not clear how to change the transmission shift schedule if an OEM chose to do so. Further, since GEM-II is modular with hierarchical layout of component layers, it is challenging for an OEM user to insert a technology improvement deep within one layer and not affect the layers above or the execution of GEM-II. It is not clear, from this initial review, how a technology improvement such as a proprietary transmission shift schedule can be evaluated in terms of gains in fuel economy and greenhouse gases. This comment applies to other technology improvements as well, such as partial engine cylinder deactivation (power on demand) or electrification of certain mechanical accessories.

a) Elements in each system used to describe different vehicle categories;

The vehicle categories that GEM-II addresses range from Class 2B to Class 8 HD conventional vehicle powertrains. This is achieved by four root-level systems in GEM-II at the root level, namely: the ambient, driver, vehicle, and powertrain modules. Each of the aforementioned modules consists of several sub-modules organized in a hierarchical manner. Each root-level module outputs a data bus that is muxed into a single data bus. The aforementioned four main systems of GEM-II correspond to the four main components of a HD vehicle, namely: driver, ambient conditions, vehicle chassis and powertrain modules. This one-to-one correspondence between the root-level GEM-II models and an actual HD vehicle makes for an easily understandable structure. Further, the modular organization of the GEM-II contributes to easier debugging and isolation of a numerical problem during simulation.

The powertrain module is the most populated module in GEM-II. It contains the engine, transmission and driveline sub-modules and accessories (mechanical and electrical). The flow of data information corresponds to an actual vehicle powertrain, with the engine output driving the transmission, which in turn drives the driveline components.

The modular layout of GEM-II, its correspondence with a real conventional vehicle is therefore appropriate and complete for the reasons stated above. The modular structure and the hierarchical arrangement of modules to mimic a real vehicle system makes the integration of additional modules and capabilities easier to implement. The signals are clearly marked and follow a logical naming convention that facilitates the addition of additional modules and capabilities into GEM-II.

b) Performance of each component model including the reviewer's assessment of the underlying equations and/or physical principles coded into that component;

GEM-II follows the model of a single wheel with a concentrated mass at the center of the wheel. The physics coded into the modules are based on Newton's second of motion for this concentrated mass. At the time of this review, no other dynamic equations were found in GEM-II, except in the clutch and torque converter. The engine, accessory, transmission and driveline components are characterized by steady state maps. The equivalent mass of rotating inertia components are also correctly included in the vehicle module of GEM-II. Rotating inertias are correctly reflected downstream to the tire. The inertia is converted to a virtual mass which is added to the entire vehicle mass. The wide validation of GEM-II against real vehicle data indicates that the physics has been correctly implemented in GEM-II.

c) Input and output structures and how they interact with the model to obtain the expected result, i.e., fuel consumption and CO2 over the given driving cycles;

Input for GEM-II:
A structure format is used to store the inputs to create the input data for the execution of GEM-II. The structure format is organized as follows: component.variable.units. For example, the input variable "engine.idle_fuel_map_speed_radps" identifies the engine speed vector of the engine idle fuel map expressed in rad per sec. Similarly, the input variable "transmission.clutch.input_inertia_kgm2 refers to the clutch inertia of the transmission, expressed in kgm2. This format follows good coding standards, making the inputs easy to pair to the appropriate component it refers to, the particular variable name, and the units used. Further, a modular approach is used to store the input data for each component in separate easily identified files in the "param_files" folder.

Output for GEM-II:
When the workspace has been populated with the input data, the simulation model "REVS_VM vehicle model is executed over the user-selected drive cycle. Each major component model (GEM_CVM, vehicle, driver, ambient) has a bus_out output port which contains a structure of component output data, which is used within other components. In addition, GEM-II uses a datalog structure to store simulation output data for later post processing to calculate emissions and fuel economy. All the simulation output is stored in a single datalog structure with multiple fields, each describing the component that the data pertains to. For example, datalog.vehicle.speed_mps refers to data log from the vehicle component of the variable vehicle speed in m/s. This format is an accepted coding standard within other vehicle simulation packages (such as PSAT from ANL, RAPTOR from SwRI) as well, making the output easy to pair to the appropriate component it refers to, the particular variable name, and the units used. Similarly, all variables that are used to perform an energy balance are prefixed by "audit".

Interaction with the model to obtain the expected results:
The bus_out structure from the various components are stored in "goto" blocks which are paired with "from" blocks to distribute data from one block to another. The use of paired "goto" and "from" blocks is an accepted method of decluttering the simulation model and avoiding crisscrossing signal lines, thereby significantly facilitating the understanding of information flow from one component to another.

d) Default values used for the input file, as shown in "Vehicle Simulation Model" document.

The default data used in GEM-II is complete and appropriate to execute a simulation of HD vehicle powertrain over one of the drive cycles available in the GEM-II default drive cycle library. The default ambient conditions summarized in ambient_param.m are appropriate. The default driver parameters, summarized in driver_param.m, contain driver gains as well as the time that the driver can look ahead in the drive cycle. The driver gains represent an average driver, which the user can change to emulate an aggressive driving pattern versus a calmer driver.

The default engine maps of 270 kW, 345 kW, and 455 kW power ratings includes inertia, idle speed. Default transmission maps for the manual, automatic, auto-manual are also available. Default tire radius, axle ratios, rolling resistance of the tires of the steering axles and drive axles are also included.

3. When using the standard of good engineering judgment, is the program execution optimized by the chosen methodologies?

Overall, GEM-II uses industry accepted coding practices throughout the software modules. The following is a partial list of these accepted practices:

- Valid variable naming structure used –
- Data bus used for each component –
- Modular components with no signals crossing –
- Useful comments to assist the user with following the code –
- Energy audit adds to the confidence level of the results of the simulation.
- File name that is executed is echoed back to the user. If there is a simulation abort, the debug is easier
- Data that is being loaded is echoed back to the user so the user knows what data is being used.
- Component modules are linked to libraries. A change in the library module propagates to all vehicle models during execution.

At this point in the review, I do not have adequate data to comment on the execution optimization of GEM-II. Linear interpolation modules from the standard Simulink library are used within GEM-II, thereby optimizing execution. If there are any non-standard user defined functions used within the GEM-II simulation model, the execution can be made considerably faster through the use of s-functions within Simulink. At the time of this review, no S-function were found in the model.

4. Please comment on the clarity, completeness and accuracy of the intended output/results (CO2 emissions or fuel efficiency output file).

The output data from a simulation execution is summarized in a spreadsheet, which is date and time stamped, allowing the user to verify that the output data corresponds to the simulation executed. The output data contains data on which technology improvement (weight reduction, vehicle speed limiter, single drive axle, par time single drive axle, low friction axle lubrication, predictive cruise control, high efficiency AC compressor, electrified engine cooling pump, extended engine idle reduction, automatic tire inflation)was assessed, engine, transmission type, fuel economy and CO2 emissions.

The output data, summarized above, serves the original purpose of GEM-II, which is to enable users to demonstrate compliance with regulatory standards either without any modifications to the HD vehicle, or analyze the fuel economy and CO2 emissions, when one or more technology improvements are employed. However, information on the drive cycle is missing or not clearly identified. In addition, key plots of vehicle tracking the drive cycle, engine operating speed-torque points over the drive cycle, engine efficiency contour plots, transmission operating points, and other plots that assist OEMS to further fine tune the powertrain and improve fuel economy/ CO2 emissions in case of non-compliance. It would be desirable to have the results of the energy audit summarized in the output file. The date stamp column is appropriate for the user to cross check simulation runs.

5. In your opinion, are there any procedures or observations that would have added to the quality of the GEM tool? Any recommendations for specific improvements to the functioning of the outputs of the model?

The following modules will enhance GEM-II:

- A module that is able to create the input data for a GEM-II execution from a user provided spreadsheet with pre-defined tabs for the engine, transmission, drive cycle, vehicle parameters, and technology improvement. Users are more familiar with spreadsheets than the Matlab environment.
- A GUI module that guides the user to create a HD vehicle model.
- A module that allows users to select plots of key component performance. These plots may be summarized in the output spreadsheet data file.
- A more detailed explanation of all the user provided data "target.X" and the various choices available for each of the user provided data. For example, what are the choices that the user has for the variable target.veh_style ?
- GEM-II execution takes place within the Simulink environment. During execution, no feedback is provided to the user on the status of the simulation. The user is waiting on a blank screen – Percent complete of the simulation and which drive cycle is being executed would be useful feedback for the user.
- Predefined sample input data for all class of vehicles to assist users to easily modify them if necessary, since some users may not be familiar with Matlab.
- The ability to turn on the feed forward term for the driver model in case of tracking problems in drive cycles with grade.
- The ability to model accessory power draw as a function of engine speed and engine temperature. The engine cooling fan power cycle will affect fuel economy and CO2 emissions.

III. SPECIFIC OBSERVATIONS

Specific Observations on Tool Description Entitled, "Vehicle Simulation Model"		
Page	**Paragraph**	**Comment or Question**
5	2	The last sentence reads "If a manufacturer uses a hybrid powertrain for the power take-off devices, it may o make use of ….". The "o" after may is a typo
3	2	Distance compensation is critical for all vehicle simulations – Therefore, this is a good feature that has been implemented in GEM-II
6	4	Please explain what is included in spin losses, since this may not be clear to all OEM users.
9	3	The GEM-II executable is very appropriate for users who are not fluent in the Matlab/Simulink environment. Further, the executable prevents users from making any changes to GEM-II to support compliance.

Specific Observations on Electronic Model Entitled, "GEM Tool"		
Input	**Variable**	**Comment or Question**
NA	NA	Avoid taking the derivative in the Simulink models. This can cause instabilities if the signal fluctuates rapidly.