Peer Review of Electrified Vehicle Simulations within EPA's ALPHA Model

United States Environmental Protection Agency

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

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NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

EPA United States Environmental Protection Agency

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I. Introduction

As the U.S. Environmental Protection Agency (EPA) Office of Transportation and Air Quality (OTAQ) develops its programs to control greenhouse gas (GHG) emissions from light-duty highway vehicles, there is a need to evaluate the effectiveness of technologies likely to be used to meet these standards. EPA has further developed the Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) vehicle simulation model to perform simulations for electrified vehicles. The Electrified Vehicle Simulations module of the EPA ALPHA model uses the industry standard MathWorks software products, MATLAB and Simulink (version 2020a). The entire model and all subsystems are unlocked for complete transparency. A comprehensive peer review of the new ALPHA simulation capabilities of electrified vehicles is imperative to assess the technical approach and accuracy of the ALPHA model as EPA's regulatory data analysis tool by the regulated light-duty automotive vehicle community.

EPA's guidelines specify that all highly significant scientific and technical work products shall undergo independent peer review according to specific agency protocols. This process is designed to ensure the use of the highest quality science in its predictive assessments and to assure stakeholders that each analysis/study has been conducted in a rigorous, appropriate, and defensible way. Therefore, EPA submitted the model for external peer review to assess whether the model has been developed in a rigorous, appropriate, and defensible way.

The peer review was conducted from June to November 2022 in accordance with the current version of EPA's *Peer Review Handbook*.[1] At the conclusion of the review process, ICF collected all unedited peer reviewers' comments and provided them to EPA. This technical report contains a summary of the reviewers' comments to EPA's charge questions, along with the unedited answers presented by each peer reviewer. The document also describes how peer reviewers were selected, the process that ICF took to administer the peer review, and how the peer review was concluded. Supporting documentation collected from the reviewers, including their curriculum vitae (CV) and conflict of interest (COI) statements, is also provided.

The following materials are included in this technical report:

- Description of the Peer Review Process (Section II)
- Reviewer Responses to Charge Questions (Section III)
- EPA's Responses to Peer Reviewer Comments (Section IV)
- Unedited Comments by Reviewers (Appendix A)
- Reviewer Supporting Documentation (Appendix B and Appendix C)
- Notes from mid-review teleconference (Appendix D)

[1] U.S. Environmental Protection Agency, Peer Review Handbook, 4th Edition, October 2015. Prepared for the U.S. EPA by Members of the Peer Review Advisory Group, for EPA's Science Policy Council, EPA/100/B-15/001. Available at http://www.epa.gov/osa/peer-review-handbook-4th-edition-2015-0, including OMB's Information Quality Bulletin for Peer Review (Handbook, Appendix B) provisions for the conduct of peer reviews across federal agencies.

- Peer Reviewer Selection Memo (Appendix E)

II. Peer Review Process

ICF conducted the peer review in three stages. First, ICF identified a qualified set of reviewers; second, ICF contracted with the selected peer reviewers and conducted the review; then, ICF collected reviewers' feedback on the model. Finally, ICF documented the peer review process, as well as the comments and feedback from the peer reviewers in a technical memo that was submitted to EPA. Ultimately, EPA will convey results of the peer review process to the developers of the ALPHA model, who will respond to the comments received. The following sections provide details on these steps.

Selecting Reviewers

To assemble the panel of three independent peer reviewers, ICF reviewed a pool of subject matter experts both suggested by EPA OTAQ and identified by ICF through independent research. ICF first assessed the experts' availability to perform the peer review within the timeline agreed upon with the EPA Task Order Contracting Officer Representatives (TO COR). After that, ICF reviewed curriculum vitae and other relevant work to select peer reviewers that represent a combined expertise that cover, at a minimum: understanding of vehicle technology packages including battery technology, hybrid and electric powertrains, e-motors, transmission systems (e.g., shift strategy), and vehicle accessories as well as engine fuel consumption map, and vehicle behavior.

The initial list of peer reviewers was based on both EPA's initial recommendations and ICF's suggestions for additional potential reviewers. Twelve candidates (five recommended by EPA and seven identified by ICF) were considered. ICF also prioritized peer reviewers based on the relevance of their background and experience with the topic of the report. Through an initial contact with the selected peer reviewers, ICF assessed each potential reviewer's ability to perform the work during the period of performance and to identify any association they have with the work that would preclude them from being objective. ICF contacted and communicated with all candidates by e-mail.

In our outreach we identified ourselves as independent contract employees and provided initial information on the ALPHA model, including the newly added electric vehicle model and the expected time commitment to exercising the model. We asked the potential reviewers to assess their availability for this study and for their hourly rate. We also collected a curriculum vitae for each peer reviewer that expressed availability and interest in participating.

Upon completion of the initial contact, the top three peer reviewers selected for this project agreed to participate in this peer review process. The rest of the peer reviewer candidates were either not available, not interested (e.g., retired), or had concerns with the limited time allocated for the review (i.e., 20 hours). The resumes for the three selected candidates were collected and shared with U.S. EPA TO COR. Upon approval from EPA TO COR, ICF initiated the subcontracting process with the selected peer reviewers.

The three selected peer reviewers (including the ICCT team) provide a diverse combination of expertise in evaluating the ALPHA model. Sujit Das, with 37 years of experience in energy efficiency research, has served as the peer reviewer of the ALPHA model back in 2016, and has published articles related to powertrain design for advanced fuel vehicle technologies. Shawn Midlam-Mohler is a Professor of Mechanical Engineering at Ohio State University, with expertise in engine selection, modeling, and control development for an extended range electric vehicles as well as vehicle simulations and powertrain optimization. Oscar Delgado and ICCT team also bring in years of experience in modeling advanced technologies and developing tools to support global commercial fleets in their transition to zero-emission vehicles.


Sujit Das


Shawn Midlam-Mohler


Oscar Delgado

*** Note that while Oscar Delgado will be our point-of-contact, ICCT has decided to review the model as a team (Oscar Delgado, John German, Hussein Basma).*

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ICF anticipated that this selected group of reviewers would provide extensive and complementary expertise to conduct the peer review. ICF provided an overview of the final list of reviewers in the July 1, 2022, Peer Review Selection Memo to EPA.[2]

Administering the Review and Receiving Comments

In conducting the peer review, ICF composed and delivered a charge letter to the three selected peer reviewers along with the model codes and documentation, and a conflict of interest (COI) form

[2] Peer Review Selection Memo for Task Order 68HERC22R0170 for Peer Review of Electrified Vehicle Simulations within EPA's ALPHA Model, to Jeff Cherry, US EPA OTAQ, from: Sam Pournazeri, ICF.

for peer reviewers to fill out and return to ICF along with their comments. The charge letter included EPA's charge questions to the reviewers, instructions on how to complete the review, and a timeline of when comments were due to ICF. ICF sent these materials to each individual reviewer on September 29, 2022. The charge questions submitted to each peer reviewer were as follows:

1) Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?
2) What is the appropriateness and completeness of the overall model structure and its components, such as:
   i. The breadth of component models/technologies compared to the current/future light-duty fleet
   ii. The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.
   iii. The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel/energy consumption and CO2 over the given driving cycles.
   iv. The use of default or dynamically generated values to create reasonable models from limited data sets.
3) Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?
4) Does the ALPHA model generate clear, complete, and accurate output/results (CO2 emissions or fuel efficiency output file)?
5) Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?

ICF then arranged and hosted a teleconference on October 6, 2022, with the selected peer reviewers and EPA. The goal of the meeting was to introduce the peer reviewers to the EPA staff and address early questions or concerns. The meeting included an overview of the review process, background information on the model, and a discussion on technical and practical aspects. ICF's notes from this meeting are included in the kick-off meeting notes that ICF shared with EPA TO COR on October 6, 2022 (Appendix D).

ICF requested that the peer reviewers provide responses to the charge questions and complete COI form within two weeks, however ICCT as well as Dr. Shawn Midlam-Mohler requested an extension of the deadline by one week, respectively. All peer reviewer comments and completed COI forms were received by October 31, 2022. ICF organized all comments into tables so that the individual comments could be easily grouped and compared for review purposes.

III. Summary of Peer Reviewer and EPA Comments

Section III presents an overview of the peer reviewers' comments received on the five charge questions, as well as a summary of EPA's responses. This overview is followed by Section IV, which provides EPA's detailed responses to the direct, unedited peer reviewer responses to each of the charge questions. In Appendix A, the unedited responses by reviewer appear in a table format. In those tables, the left column lists the EPA's charge question, and the right column provides the reviewer's comments.

Comment Overview and Summary

The following section summarizes the peer reviewers' comments to the charge questions. The questions have been abbreviated for easier presentation. These summaries do not rewrite the responses or supersede the unedited comments presented in Section IV.

All three reviewers provided additional comments beyond those requested by the five prescribed charge questions. Those are not summarized here but are presented in their entirety in Section IV.

Question 1: Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?

The reviewers found that EPA's overall approach to the stated purpose of the model and attributes embody the goals as outlined. Sujit Das added that considering that ALPHA model was primarily developed to assess the GHG emissions of internal combustion engines (ICE) light-duty vehicles, it may not be well suited to evaluate alternative pure EV technologies. Shawn Midlam-Mohler raised that ALPHA in its current state does not offer any novel features compared to the current tool portfolio in the public domain. If one goal for ALPHA model is to be widely accepted to quantify technology effectiveness and CO_2 emissions of electric vehicle technologies, Shawn warns that there may not be enough distinct features for ALPHA to be preferred over other models of its class. ICCT suggests that ALPHA developers provide greater clarification on powertrain components' characteristics and what electric motor-generator technologies they are based on. Users may be interested in the assessment of other electric motor-generator technologies that scale differently based on vehicle type. ICCT also raised a question on the exclusion of the fuel-cell powertrains from the model.

EPA Summary Response: *EPA supports the reviewers' finding that our overall approach to the stated purpose of the model and attributes embodies the goals as outlined. We also agree with Sujit Das that the earlier versions of ALPHA were focused on CO_2 production; however, implementing a pure EV model (which uses the same non-powertrain sub-models within ALPHA) was a relatively minor expansion of ALPHA's capabilities for version 3.0. In reference to Shawn's concern about the lack of distinct features, ALPHA is explicitly not intended to compete with commercial vehicle simulation products or supplant manufacturers' own modeling packages, and thus its user interface features should not be expected to be at the same level as commercial simulation tools. EPA's goal of the public release of ALPHA is to provide sufficient documentation and transparency to allow thorough review by stakeholders of EPA rulemakings. EPA also agrees that providing greater clarification on powertrain components would be useful to stakeholders. EPA is in the process of documenting the electric component data used in ALPHA modeling and will be publishing the information on a new EPA web page dedicated to electric components.*

Regarding clarification of powertrain characteristics, peer reviewers were provided four electric motor maps with detail specifications, one for use in each model (i.e., one for the BEV, one for the PowerSplit strong hybrid, one for the P2 strong hybrid, and one for the P0 mild hybrid). Any of these component maps can be scaled and ALPHA is also capable of accepting other motor maps as input. Finally, the exclusion of fuel cells is not unique. The electrified configurations currently populated within ALPHA – BEVs, PowerSplits, P2s and P0s – represent the most popular high-volume electrified configurations. Based on its analysis, EPA concluded that other currently lower volume configurations, such as series parallel hybrids, P1 mild hybrids, and fuel cell electric vehicles, were likely to remain lower volume and not significantly affect EPA's characterization of the overall future fleet

Question 2*:* What is the appropriateness and completeness of the overall model structure and its components?

The reviewers agreed that the ALPHA model's structure and its components are sufficiently appropriate and complete to achieve the stated purpose. However, each expressed that there is room for improvement across the breadth of model components, model performance, input and output structures, and use of limited data sets.

Sujit Das qualifies that ALPHA model's parameter files at the five major EV component levels are accessible, provided that users are moderately experienced with MathWorks software. Although the model as provided was unlocked for complete transparency, Sujit recommends that a separate document with equations and their descriptions would be invaluable to users regardless of MATLAB/Simulink aptitude. An explicit list of equations would enable a higher level of input data validation.

Shawn Midlam-Mohler and ICCT both agreed after an extensive look at control algorithms for the BEV and PHEV platforms that there is room for improvement. Shawn expressed concern with ALPHA's use of relatively simple rule-based control code and with the presence of some developmental comments in the control code provided to the peer reviewers. Another weakness of the current control algorithm is the relationship it has to the model's seemingly calibration-based data, which makes it difficult to discern how well components of controls can be scaled to create other reasonable models.

ICCT concluded the different technology and modeling choices are all reasonable, and special attention was given to the hybrid powertrain controllers. However, ICCT questioned whether the current control strategy for the P2-PHEV platform is representative. ICCT offered credit to the rule-based control strategy's ability to be computationally efficient but countered that there are other alternative control strategies that can better reduce total fuel and energy consumption. ICCT also posed that although constant-power auxiliary modeling, as provided, is complete and appropriate, there are recent developments in the literature that can inform ALPHA developers of how to incorporate dynamic auxiliary operation and impacts.

EPA Summary Response: *EPA agrees with the reviewers that the ALPHA model's structure and its components are sufficiently appropriate and complete to achieve the stated purpose, and improvements could be made to the ALPHA package. As suggested by Sujit Das, EPA will work to incorporate a description of the underlying equations and/or physical principles coded into components.*

EPA agrees with Shawn Midlam-Mohler that ALPHA's control code is rule-based (focused on rules observed in testing of production hybrid and battery electric vehicles) but does not view this as a concern or deficiency. EPA models representative production (or production-ready) components and control strategies that can, on average, be used to simulate the performance of the current fleet to provide reasonable CO2 and energy consumption estimates for technologies and strategies manufacturers might choose to employ in future fleets. This approach grounds our vehicle models in the actual control calibration and performance of production vehicles and avoids overlooking any design constraints present in a vehicle manufacturer implementation of new or existing technology.

In addition, EPA agrees with Shawn that any unused experimental code should be cleaned up. EPA plans to add more appropriate comments to the code but leave the commented-out code itself in place as a basis for potential future development.

ICCT commented the different technology and modeling choices are all reasonable. There was concern with the representativeness of ALPHA's P2-PHEV strategy related to the modeled control strategy. EPA constructed the P2 model based on the operation of a popular and well-performing vehicle in the fleet (in this case a Hyundai Sonata). The engine control strategy in ALPHA demonstrates a good match with test data from the vehicle operating on the regulatory cycles. Although other more optimal control strategies may become available in the future, for the purposes of the current rulemaking, EPA incorporated vehicle components and control strategies that already exist within the current fleet and are representative of the performance of a broad range of vehicles.

Question 3: Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?

The three reviewers expressed that although the general approach ALPHA model takes is sound and comprehensive, that some of the techniques and priorities of the model could be shifted to provide greater functionality without much compromise. Sujit Das shared that in one instance, he experienced a model run-time exceeding 10 minutes, without indication of progress through the duration of the run.

Although Shawn found that ALPHA model as-is delivers fast program execution, he countered this goal with a suggestion for developers to implement more complex control algorithms to potentially increase model run-time. Rather than prioritizing time-savings during model execution, Shawn proposes that ALPHA model with more complex control algorithms achieves parity with current run-times since users will spend less time calibrating and validating data overall.

ICCT initially stated they could not determine if the ALPHA model uses good engineering judgement without a thorough comparison between simulation results and real-world testing data at the component and vehicle level. After discussing their comment with EPA, ICCT concluded the general approach of using real-world testing data in the model validation process was reasonable and the modeling run demos provided by EPA demonstrate good agreement between simulation results and real-world data, but a more robust assessment was beyond the scope of their peer review.

EPA Summary Response: *EPA agrees with reviewers that the general approach ALPHA model takes is sound. The runtime experienced by Sujit Das was primarily due to the setup of the demo cases sent to the reviewer, which logged every signal and recompiled between runs. In larger batch simulations, runtimes are generally quite short for each simulation. The more complex algorithms proposed by Shawn Midlam-Mohler might be valuable to some users, but EPA does not have the need to implement these types of algorithms in support of current regulatory work. The current algorithms are relatively simple in part due to the purposeful replication of the narrow vehicle operating conditions occuring during hot start EPA regulatory cycles (e.g., room temperature, no HVAC, warmed up operation, etc.). EPA agrees with ICCT that a robust, deep-dive assessment of model fidelity through the comparison of simulation results and real-world testing data is a time-consuming task, and notes that each sub-model within ALPHA was thoroughly validated against component and system data collected from vehicle dynamometer testing by EPA's laboratory and by others.*

Question 4: Does the ALPHA model generate clear, complete, and accurate output/results (CO2 emissions, or fuel efficiency output file)?

The three reviewers found that the output results and output files are labeled appropriately and are relatively complete. Shawn Midlam-Mohler noted that "results" are generated across log files, console output, and figures, which should provide users with a good amount of summary and detailed results. However, Shawn and ICCT note a few user-friendly changes that ALPHA model developers should consider making or need to make. For example, some of the plots automatically generated are missing axes labels, making what is to be interpreted unclear. Other user quality of life enhancements could organize console output as .csv files so that users do not have to copy, paste, and reformat data for their specific purpose. ICCT suggests that certain data, such as energy consumption metrics, should be disaggregated by component so as for ALPHA model to provide more clear and complete evaluations.

EPA Summary Response: *EPA agrees with reviewers that output results and output files are labeled appropriately and are relatively complete. EPA also agrees that some figure axes were not properly labeled and will update the scripts in ALPHA to ensure axes contain units. For the console output, the data are primarily intended to be used for diagnostics and are formatted for that purpose. While console values were not included in the peer review output files, they are accessible in the workspace and thus could manually be added to the CSV result files if desired.*

The accessory energy consumption referred to by ICCT can be defined by the user either for each component individually or as aggregated energy consumption of all accessories. For the peer review, the aggregated energy consumption was defined as a single generic loss, whose value is derived *from chassis dynamometer test data. Users may instead choose to define losses disaggregated by component.*

Question 5: Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?

All reviewers fall in alignment with ICCT's specific recommendations. For example, reviewers expressed that better model documentation, particularly regarding equations and modeling assumptions, be made available in the next iteration of ALPHA model. In the additional comment section, Shawn mentioned that the model documentation was very much focused on the programming structure of the model and not much on the actual modeling approach. He noted that for others to adopt the methodology developed by EPA, these details need to be readily available to the users.

The ICCT reviewers also found through their experience with ALPHA model that one "master" input file would expediate initial model parameterization. Additionally, reviewers expressed some concern or curiosity regarding the core data used to develop the vehicle models. Some aspects of the ALPHA model, such as its robustness or fidelity to alternative vehicles and emissions, will gain greater approval and acceptance when the underlying data are made available for users to understand the breadth of validation against real-world data.

EPA Summary Response: *EPA agrees with reviewers that additional documentation would be useful to include in the next iteration of ALPHA, especially on the modeling approach, and will work to do so. Some additional model details have been included in previous EPA publications, which were not included with the ALPHA documentation, but will be integrated into the ALPHA manual to be readily available for future users.*

Referring to ICCT's comments, EPA notes that ALPHA includes a batch processing script where all inputs can be listed and multiple simulations can be performed, thereby expediating initial model parameterization. EPA also agrees with the reviewers that explaining core data collection and its relevance is essential for a robust, transparent modelling process. EPA is in the process of documenting the electric component data used in ALPHA modeling and will be publishing the information on a new EPA web page dedicated to electric components.

IV. U.S. EPA's Responses

ICF forwarded all peer reviewers' comments as a draft report package to EPA for their review. Upon reviewing the comment, EPA provided detailed responses to peer reviewers' comments that are listed in this section of the report. The remainder of the document contains responses from ALPHA Model development team. EPA organized responses to the peer reviewer comments grouped by charge letter questions, addressing each reviewer's comments.

Summary Observations By EPA

EPA's responses included additional information regarding a) the purpose of ALPHA, b) the reasoning behind releasing ALPHA and its associated documentation to the public, and c) the goal for this ALPHA peer review. The intent of the additional information is to provide further clarifications and helpful context for EPA's responses to specific peer review comments associated with public use of the simulation tools, supporting documentation for ALPHA model structure and execution, and the user-friendliness of the tool.

ALPHA's Purpose

EPA uses ALPHA for regulatory purposes to simulate the CO_2 emissions and energy usage of vehicles in the current fleet and potential future fleets. EPA recognizes there are a wide variety of vehicle components and control strategies within the fleet, both in conventional and electrified vehicles. Rather than precisely simulate all aspects of every vehicle, ALPHA uses a limited library of vehicle components and control strategies to reasonably represent performance across the fleet. This approach endeavors to strike a balance between two separate goals – to precisely simulate the performance of every vehicle while also having an easily adaptable model capable of delivering acceptable vehicle simulation results across a vast variety of known current, and unknown future, vehicle fleets.

To meet the simulation needs for EPA's regulation development, ALPHA was designed with a fit-for-purpose approach that does not require precise implementation of all control strategies for each current and future vehicle variation. Rather, EPA selects representative production (or production-ready) components and control strategies that can, on average, be used to simulate the performance of the current fleet to provide reasonable CO_2 and energy consumption estimates of the technologies and strategies manufacturers might choose to employ in a future fleet. This approach grounds our vehicle models in the actual control calibration and performance of production vehicles and avoids overlooking any design constraints present in a vehicle manufacturer's implementation of new or existing technology. This approach to fleet simulation is very similar to the approach EPA has taken in the past to model conventional vehicles for the current fleet[3] and the future fleet[4].

Although ALPHA can easily incorporate a wide variety of component maps, to simplify the peer review process only one version of each type of component was supplied to the peer reviewers. Likewise, each model included in this peer review contained a typical control strategy and a single calibration. These can be altered by the user; however, the strategy and calibrations provided in the peer review models reflect those used in the operation of well-performing vehicles that are

[3] Kevin Bolon, Andrew Moskalik, Kevin Newman, Aaron Hula, Anthony Neam, and Brandon Mikkelsen, "Characterization of GHG Reduction Technologies in the Existing Fleet," *SAE Technical Paper 2018-01-1268*, 2018

[4] Andrew Moskalik, Kevin Bolon, Kevin Newman, and Jeff Cherry, "Representing GHG Reduction Technologies in the Future Fleet with Full Vehicle Simulation," *SAE International Journal of Fuels and Lubricants,* 11(4):469-482, 2018)

representative of their type of configuration (P0 mild hybrid, P2 or PowerSplit strong hybrid, or battery electric vehicle).

Reason for ALPHA and Associated Documentation Release to the Public

Although ALPHA is primarily used by in-house EPA experts in support of regulatory development programs, it is publicly released in conjunction with proposed rulemakings to increase transparency. ALPHA is not intended to be used as a general-purpose vehicle simulation model when versions are released to the public. Instead, ALPHA intentionally incorporates only features needed to estimate CO2 emissions and energy consumption over the US EPA regulatory drive cycles under laboratory conditions as specified under the proposed rulemaking. EPA does not require, for example, the additional fidelity or flexibility to estimate real world in-use emissions.

The goal in posting versions of ALPHA on the EPA website is to provide sufficient documentation to allow transparent review by stakeholders of our rulemakings. ALPHA's documentation and user interface are intended to allow the public to observe and review the simulation inputs, modeling assumptions & behavior, and simulation outputs as a mean of understanding how the ALPHA simulations were conducted in support of EPA's regulatory programs. ALPHA is not intended to produce wide-ranging, detailed vehicle simulations like those generated by commercial simulation tools (such as Autonomie, GT-Drive and AVL Cruise). For this reason, overall documentation, user interface features, and user support for the ALPHA tool should not be expected to be at the same level as commercial simulation tools.

Likewise, the ALPHA interface and documentation are not created for the novice user and do require some expertise in both vehicle modeling and MatLab usage. The ALPHA documentation and user interface provided should allow experts in the automotive community to re-create provided simulations using their own in-house simulation tool, a commercially available tool, or even ALPHA. The model itself is fairly straightforward and the MatLab data Classes provide formatted documentation for most critical components.

The Goal of ALPHA Peer Review

The goal for this ALPHA peer review is to examine the structure, operation, and simulation results used by EPA to determine the effectiveness of various technologies via simulation. The examination of this peer review is centered on ALPHA's recently added electrified vehicle models:

- Battery electric vehicle (BEV) model
- PowerSplit hybrid vehicle model
- P2 hybrid vehicle model
- P0 hybrid vehicle model

In its performance work statement to peer-reviewers, EPA requested "*the reviewer's opinion of the* concepts *and* methodologies *upon which the model relies and whether or not the model can be expected to execute these algorithms correctly*". The documentation and user interface provided for the peer review (and planned as part of the ALPHA release in conjunction with our current rulemaking) were primarily intended to allow observation and review of the structure, operation, and simulation results of the supplied electrified models. Although the documentation and user interface provided was not intended to be the focus of the peer review, EPA welcomes comments on these aspects to help guide future development of ALPHA.

Responses to Peer Reviewer's Comments by Charge Question

In this section, comments from the peer reviewers are grouped by charge letter topic. EPA's responses to each reviewer's comments by charge letter topic are shown below.

Question 1: Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?

Peer Reviewer: Sujit Das

A. Four major types of electrified vehicles have been considered in ALPHA and it is appropriate that the ALPHA simulations of two most important vehicle types (i.e., BEV and PowerSplit HEV) in the near-term have been selected for the peer review. Of the electrified vehicles, U.S. DOE/EIA projects new BEV sales increase faster than any other type of battery-powered vehicles, both electric hybrid and 300-mille electric vehicles reaching at ~1.2 million/year and both BEVs and PHEVs combined would account for 13% of total LDV sales in 2050, according to the AEO2022 reference case.

   EPA Response: *Thank you for the comment; EPA agrees with the reviewer's assessment of the two most important vehicle types.*

B. As ALPHA model has been primarily created to evaluate the GHG emissions of ICE Light-Duty vehicles, it is less appropriate to evaluate alternative pure EV technologies. It is also to include other specific electric vehicle types, i.e., sedan, SUV, CUV, and pickup in the future model updates.

   EPA Response: *ALPHA was primarily created to simulate vehicle behavior on regulatory dynamometer cycles. Although the first iterations of ALPHA were focused on CO_2 production, implementing a BEV model, and tracking electrical energy usage was deemed to be a minor expansion of ALPHA's capabilities. In fact, the non-powertrain sub-models within ALPHA are used to simulate both conventional and electrified vehicles.*

   Additionally, the vehicle package included in the ALPHA model sent to peer reviewers included a set of vehicle parameters which reflected a specific generic vehicle. These parameters can be altered to model any other vehicle; thus, the capability to simulate the behavior other specific electric vehicle types, such as sedans, SUVs, CUVs, or pickups, is a capability that already exists within the ALPHA model.

Peer Reviewer: Shawn Midland-Mohler

A. The scope of the review is focused mainly on the BEV model and the PowerSplit HEV model with a secondary focus on the Strong P2 HEV and the Mild P0 HEV model. In all of these cases, the modeling approach is able to meet the goal of modeling energy consumption. I have concerns about the current state of the model with some concerns about how the control algorithms are implemented.

   A main concern is regarding the likely adoption of this model or the utility for the intended purpose given the observation that: a) this class of model is already in the market; and b) the vehicles that this model focuses on (BEV, PowerSplit HEV, etc.) are available from many OEMs and, thus, there performance across many different vehicle classes is well-understood.

   The modeling approach used is typical to that used in industry and academia, thus, it is appropriate. However, the approach also does not lend itself to easy adoption outside of expert users. In general, people with sufficient expertise to modify this type of model and yield reasonable results likely already have existing models available to them. One of the stated goals is that ALPHA will gain wide acceptance in the light-duty vehicle automotive community, and I do not feel that is likely to occur in the current implementation.

   EPA Response: *The intended purpose of ALPHA is to support EPA's regulatory actions in a robust and transparent way. ALPHA is explicitly not intended to compete with commercial vehicle simulation products or supplant manufacturer's own modeling packages. The goal of the public release of ALPHA is to provide sufficient documentation to allow transparent review by stakeholders of the rulemaking. ALPHA's documentation and user interface are intended to allow the public to observe and review the simulation inputs, modeling assumptions & behavior, and simulation outputs as a means of understanding how the ALPHA simulations were conducted in support of EPA's regulatory programs. For this reason, the overall documentation and user support for ALPHA should not be expected to be at the same level as commercial simulation tools (such as Autonomie, GT-Drive and AVL Cruise).*

B. The model approach is very similar to that used in Autonomie which has the benefit of many years of development. A main feature in Autonomie that distinguishes it from ALPHA is the availability of a GUI for model creation, modification, and data analysis for users to exercises models. The ability to scale component models via a GUI, queue up different drive cycles, adjust control parameters, etc. seem to make it better suited for the intended purpose. Autonomie also has a more robust library of component options as well as more robust control algorithms.

   Because of the availability of tools like Autonomie, in-house tools, commercial tools like AVL Cruise, and even example models provided within MATLAB, it is unclear how ALPHA in its current form will meet the objectives. To be very clear, the technical approach of ALPHA seems to be sound. My concerns are that it is not providing a solution that is not already in the market with more established products.

   EPA Response: *EPA agrees the modeling approach is very similar to that found in Autonomie and appreciates the reviewer for recognizing the technical approach taken with ALPHA is sound. The intended purpose of ALPHA is to support EPA's regulatory actions in a robust and transparent way and explicitly not compete with available commercial products. We recognize that Autonomie, AVL Cruise, and other packages, as commercial tools, may have a more user-friendly interface and a larger library of components and algorithms.*

C. Furthermore, the marketplace now has a wide variety of electrified vehicles available and there is data associated with these vehicles in the public domain. Organizations have access to this data from their own vehicles as well as competitor assessments. From a planning perspective, it is not clear what a model like this is able to provide. In the area of BEVs, the increasing offering from many OEMs gives us the ability to reliably estimate things like range and energy consumption based on actual vehicle data.

EPA Response: *ALPHA is used to support regulation development, which requires projections of CO2 emissions and energy usage in future years as the US vehicle market adapts to consumer demand and regulatory requirements. The simulation models in ALPHA were developed using actual electrified vehicle data and performance. ALPHA can then be applied to simulate vehicle configurations anticipated in future fleets but not necessarily currently available. Because the model inputs, vehicle parameters, and outputs are transparently provided in support of EPA's rulemaking, any of the commercial tools (or a stakeholder's own in-house tool) can be used to re-create the simulations provided to the public.*

D. The core energy consumption of the energy storage system and traction motors which ALPHA focuses on is quite well understood and apparent from test data that is in the public domain via certification requirements. Aspects like HVAC load, battery cooling during fast charging, etc. which are areas which are more challenging which can significantly impact real-world energy usage and range are not well modeled in ALPHA or most models.

EPA Response: *EPA agrees these effects could be modeled better in ALPHA and most other models. However, the focus of ALPHA is on vehicle performance over room-temperature regulatory cycles, where the effects from the aspects highlighted by the reviewer above are not a factor. We believe that possibly incorporating these effects into future versions of ALPHA may be appropriate, to the extent that actual on-road emissions and/or energy consumption becomes important to directly quantify in any future rulemaking program.*

E. None of the above should be taken as a comment on the modeling approach or skills of the developers. The approach seems to be typical of the class of models that others have deployed for this purpose. The main concern is if ALPHA will serve the intended purpose in terms of being impactful in the technical community. Given the availability of public domain data on these vehicles, the availability of internal data on their own vehicles to OEMs, the availability of competitor assessments, and the availability of other simulation products capable of the same type of analysis it is not clear how widely this tool will be used.

EPA Response: *EPA does not expect ALPHA to be used widely in place of other commercial simulation packages or manufacturer's internal tools. Rather, we hope the impact is through the acceptance of ALPHA's simulation inputs, modeling assumptions & behavior, and simulation outputs in support of EPA's the regulatory analysis. The goal is to provide enough information that allows direct comparison of ALPHA simulation results to similar simulations or estimates completed by any stakeholder's internal analysis.*

Peer Reviewer: ICCT

A. The proposed model looks comprehensive and of high fidelity enough to serve its purpose of quantifying the fuel economy, energy efficiency, and CO2 emissions of different powertrain typologies under a variety of operating conditions for several technology choices.

EPA Response: *Thank you for the comment; EPA agrees.*

B. The main issue that needs clarification at this stage is the powertrain components' sizing and scaling approach. The process seems to be technology agnostic. For example, in the case of electric motor-generator scaling, the model appears to rely on one electric motor data-driven model reflecting a specific motor technology. We are not sure if this is only the case for the shared demo version of the tool and if the complete ALPHA model already includes several components' technologies. If that is the case, please disregard this comment.

EPA Response: *Thank you for your comment. EPA agrees ALPHA's sizing and scaling approach deserves clarification and will provide more explanation of our sizing and scaling methodology as part of the Regulatory Impact Analysis for our current rulemaking. The version of ALPHA provided to the peer reviewers included four electric motor maps, one for use in each model (i.e., one for the BEV, one for the PowerSplit, one for the P2, and one for the P0). Any of these component maps can be scaled to model a component of different power. We believe these component maps are reasonably representative of the motors used in industry; however, ALPHA is also fully capable of accepting other motor maps as input. EPA has used alternate component maps to simulate specific vehicles, some of which contain CBI and cannot be publicly released. We did utilize these alternate component maps to confirm our conclusion these four electric motor maps are reasonably representative of the motors used in the industry.*

C. While the model is clear regarding technology choices focusing on hybrid-electric and pure-electric powertrains, it remains unclear why fuel-cell powertrains are excluded from the model.

EPA Response: *When choosing which electrified configurations to include in ALPHA, EPA surveyed which configurations existed in the current fleet. The most popular high-volume configurations – BEVs, PowerSplits, P0s, and P2s – were chosen for inclusion in ALPHA. Other currently lower volume configurations – series parallels, P1s, and fuel cell electric vehicles, for example – have not been included but may be candidates for inclusion in future versions of ALPHA, especially if their market penetration increases.*

Question 2: What is the appropriateness and completeness of the overall model structure and its components, such as:
2a) The breadth of component models/technologies compared to the current/future light-duty fleet
2b) The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.
2c) The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel/energy consumption and CO2 over the given driving cycles.
2d) The use of default or dynamically generated values to create reasonable models from limited data sets.

<u>Peer Reviewer: Sujit Das</u>

A. ALPHA model is fairly straight forward tool only for an experienced MATLAB user for understanding vehicle behavior, greenhouse gas emissions and the effectiveness of various powertrain technologies of current and future vehicles by appropriately changing input values in five major vehicle parameter files. Parameter files are organized at the level of five major EV components, i.e., Base (Driver and Controls), Vehicle, Electrical, Accessory, and Transmission for running a desired EV technology. Battery and the electric machine are a part of the Electrical component. The ALPHA model is currently limited to CO2 emissions for five different EPA driving cycles including custom driving cycles based on test fuel properties and vehicle fuel consumption.

EPA Response: *EPA agrees that fully exercising ALPHA requires some experience with MATLAB; the ALPHA interface and documentation are not created for the novice user. Additionally, although earlier versions of ALPHA are limited to simulating CO2 emissions from vehicles with IC engines, with the incorporation of electrified models into ALPHA the model can now also simulate electric energy consumption. Although the version of ALPHA provided to peer reviewers included the city, highway and US06 regulatory drive cycles, any pre-defined drive cycle may be incorporated into ALPHA and used in the simulation.*

B. An assessment of the underlying model equations and/or physical principles couldn't be made as they were limited to the original Simulink code without any appropriate model documentation available including the limited peer review time. ALPHA model 0.2.0 documentation is an excellent resource for a MATLAB model user in terms of the contents of various files, but no description of types of equations including the source and validation of the equation parameter values used. A Data Dictionary of variables used in the model would be useful for better understanding of a novice user.

EPA Response: *EPA agrees that information on the model equations and/or physical principles is not currently contained in the documentation provided for the peer review and can only be found in the Simulink code. In an updated version of the ALPHA documentation, EPA will work to incorporate a description of the underlying equations and/or physical principles coded into components, along with additional overview information we plan to include in our Regulatory Impact Analysis.*

C. The model is completely input data driven, which need to be collected by either engine or chassis dynamometer testing by specific vehicle system technology case. The model application is thereby limited to the extent of validated data availability. The overall model performance is dictated by calibration of numerous technology-specific parameters used to determine final vehicle fuel economy and CO2 emissions for various vehicle drive cycles.

EPA Response: *EPA agrees ALPHA is data driven and limited by (or dependent on) data availability. EPA believes this approach is appropriate for a model used to support regulatory activities, as our projections are based on real world information. The majority of ALPHA inputs are built from component and vehicle benchmarking conducted on production vehicles, while others are derived, and quality checked using data in technical reports and papers based on work done by others. ALPHA's electrified models were calibrated against specific, popular, and well-performing vehicles that contain technology packages considered reasonably characteristic of the overall fleet. While EPA recognizes there are a wide variety of unique components and operational strategies in the fleet, EPA has concluded that modeling these representative examples of various configurations, and not every variation, is sufficient for our purposes in characterizing a potential future fleet. However, it is important to note ALPHA was constructed to easily allow incorporation of any data or control parameters made available from stakeholders which might improve our projections.*

D. The input structure is defined by five major component MATLAB files, in which the input parameter values can be changed for the simulation of new technologies. The expected results of fuel/energy consumption and CO2 over the given driving cycles for the two vehicle types reviewed were reasonable. For PS HEV HWFET drive cycle, CO2 emissions was estimated to be 4%-21% higher than for the UDDS cycle.

EPA Response: *Thank you for the comment; EPA agrees.*

E. The use of default or dynamically generated values could only be assessed by the final summary output results. A documentation on the approach and the sources used for the input parameter values would be useful for the model user to develop or any new technologies.

EPA Response: *The default values used in ALPHA are primarily derived from data taken during chassis dynamometer testing. These specifically include hybrid control parameters, accessory loads, and battery pack parameters. Those few values which are not based directly on test data (for example, the boost converter losses in the powersplit model) are taken from published research. EPA agrees that documentation on the approach and sources for default or dynamically generated values within ALPHA could be improved and will work to do so.*

Peer Reviewer: Shawn Midland-Mohler

A. Overall, the model has the overall systems that one would expect for the stated goal. Given the importance of HVAC and battery thermal management to BEV and PHEV platforms, this is one area that is not well-developed in the model. The mechanical and electrical accessories are divided into four sub-models, generic loss, power steering, air conditioning, and fan loss. In the BEV model, there was no energy usage associated with the engine fan, power steering, or air conditioning system. This could indeed be the case; however, the modeling approach is map-based and would require this information to be specified by the user. Given that the loads from these systems can cause significant reductions in in-use energy efficiency, higher fidelity of these models would certainly add to the capability of the model.

EPA Response: *ALPHA is used to simulate room-temperature regulatory cycles performed on a chassis dynamometer with the HVAC system turned off. In this case, there are no losses due to HVAC loads, although ALPHA does provide a tunable parameter to represent those losses if the user wishes. For the remaining losses, rather than individually modeling them, the effects of all accessory losses (including energy used for battery thermal management) are combined into one generic accessory load, whose value is set based on vehicle test data. However, EPA agrees higher fidelity modeling of accessory losses would enhance ALPHA's capability and plans to begin developing ALPHA's battery thermal management modeling (especially for BEVs) to support potential future regulations.*

B. The control models deployed in the models reviewed also poses a challenge. As with any model of this class, a controller is necessary to manage the torque split and gear as well as other important vehicle functions. The quality of the control algorithm can have a major impact on the efficiency of the simulated vehicle – a great vehicle component design with a marginal control algorithm/calibration will perform marginally. There are optimization techniques that have been applied to this class of models to allow a more refined control to be deployed without excessive calibration by the user.

EPA Response: *EPA agrees the quality of the controller affects the efficiency of the vehicle. The electrified models in ALPHA were calibrated against specific, popular, and well-performing vehicles in the fleet that contain technology packages reasonably characteristic of the fleet as a whole, and the control algorithms in the model replicate the behavior of* *these vehicles. Although other techniques could be used, EPA chose to replicate the behavior of manufacturer-calibrated vehicles rather than optimize their efficiency. This approach ensures that all NVH and other reliability issues that manufacturers must consider are accounted for in the calibrations used in our simulation.*

Additionally, ALPHA is used to simulate room temperature dynamometer cycles rather than in-use operation where much of the calibration complexity resides. EPA does not intend to implement numerous calibration packages for each electrified vehicle, but instead plans to use fewer calibrations that are reasonably characteristic of the performance of the whole fleet over dynamometer regulatory cycles. However, EPA does recognize the advantage of implementing an optimal control algorithm which perhaps dynamically tunes its behavior for both the powertrain and drive cycles mirroring further technological advances in industry and will consider doing so.

The control algorithm used for the Power Split vehicle was inspected which is in the PS_control.m function. The "working" part of the code consists of less than 100 lines of code and is what one would refer to as rule-based for the most part. There are comments included that say "% ::What is this?" and "% ???" which I can understand as a person who has done these things before – but also does not lend confidence in the maturity of the control algorithm provided. Given the importance of control algorithms for predicting the efficiency of vehicles it is critical that these be matured.

***EPA Response**: EPA agrees the working code in PS_control.m consists of about 100 lines of rule-based code. Please note there are additional sources of code associated with PowerSplit hybrids throughout ALPHA.*

To meet the narrow simulation needs for EPA's regulation development, ALPHA's control strategies were designed with a fit-for-purpose approach. As a result, they do not require full and precise implementation of all possible control strategies for current and future vehicle variations, over every operating condition. For example, ALPHA only needs to simulate vehicle operation at room temperature, over standard regulatory drive cycles. In addition, ALPHA needs to simulate production (or production-ready) components and control strategies that can, on average, be used to replicate the CO2 and energy consumption estimates of the current fleet (which are ultimately used to forecast what technologies and strategies manufacturers might choose to employ in a future fleet).

This control strategy approach grounds our vehicle models using specific vehicle data that reflects production control strategies and calibrations which meet the performance of production vehicles, thereby including the performance results due to design constraints incorporated in a vehicle manufacturer's implementation of new or existing technologies.

EPA agrees the comments quoted are uninformative. The portion of the code referenced contains experimental code with an alternative methodology for determining additional emissions from hybrids during an FTP cold start and was not being used functionally. EPA eventually opted to use a post-processing adjustment for the cold-start FTP (similar to the one used for conventional vehicles) and ceased work on the alternative methodology but did not remove the associated code. The comment remained from the time when the code base was being refactored and cleaned, as a method of communicating within the coding team, and reflects the work-in-progress state of the code. Rather than delete this section of code, EPA will clean up the code, add comments, and leave the code as a basis for potential future development.

C. Overall, this is more or less an implementation of a force balance on the vehicle. The components are modeled via maps and the basic relationships between the components. No errors were noted in the summation of torques/forces that acted on the vehicle inertia. A model of this class relies on appropriate component maps and appropriate controls. Without a more rigorous look at these with comparison data it is not possible to provide a full assessment of this.

   When inspecting the driver commands (brake and accelerator) and high-level control inputs like gear shifts and torque commands, I did not find anything of concern. Depending on the underlying control algorithm and driver model, there can sometimes be high-frequency behaviors on these signals that are not representative of actual vehicle controls or driver behaviors. This was not noted in the model outputs reviewed.

   EPA Response: *EPA agrees with the reviewer on these points. We have intentionally tuned the driver model to avoid these high-frequency behaviors. Additionally, the ALPHA shifting algorithm was developed to replicate actual vehicle behavior and has not exhibited these behaviors. (See, for example: Newman, K., Kargul, J., and Barba, D. (2015) "Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation," SAE Int. J. Engines 8(3):2015, doi:10.4271/2015-01-1142.)*

D. I was not able to find much documentation on the actual models used outside of the overall vehicle mass and loss model. This made it challenging to review the modeling approach as it needed to be interpreted from the model and input/output.

   EPA Response: *EPA agrees information on the modeling approach was limited in the documentation provided for the peer review. EPA plans to share more details on the modeling approach in an upcoming technical paper, but the content of this was not available prior to the peer review. Additionally, EPA plans to include a description of the model architecture, model inputs, and simulation results in comparison to validation vehicles and similar vehicles in the fleet in its Regulatory Impact Analysis (RIA) supporting the upcoming rulemaking. Finally, EPA plans to add some of the content from the technical paper and RIA to the ALPHA documentation.*

E. I provided very detailed comments on the output in response to the fourth Charge Question below. In this discussion, I will focus on the input structures. In the demo files provided, the input structure was clearly defined and using variants in the model appropriate subsystems were enabled.

   It was not clear to me if there was scaling that could be applied in the input structure – there did not appear to be. That is one aspect that is generally quite useful to be able to slightly adjust component sizes without having to generate new component data files.

   EPA Response: *Any of the component maps within ALPHA can be scaled to model a component of different power. EPA agrees ALPHA's sizing and scaling approach deserves clarification and will provide more explanation of our sizing and scaling methodology as part of the Regulatory Impact Analysis for our current rulemaking.*

F. Compared to more mature projects like Autonomie, there are not many options. The capability is there, but I did not locate any library of models or the ability to scale them. Likewise, the control algorithms were very likely highly specific to the particular set of components they were calibrated to work with. I was not able to locate documentation on the nature of the controls but after inspecting the model and the input files it seemed to be very calibration-based.

EPA Response: *ALPHA is built on component and vehicle mapping conducted on specific production vehicles. EPA recognizes there are a wide variety of components and operational strategies in the fleet. Although EPA plans only on modeling representative examples of various configurations and not every variation, ALPHA was constructed to allow stakeholders to incorporate their own data if they wish.*

Peer Reviewer: ICCT

A. The different technology and modeling choices are all reasonable. Special attention has been given to the hybrid powertrain controllers, one of the main fuel economy drivers.

The P2-PHEV controller, as an example, seems to utilize a charge-depleting charge-sustaining strategy depending on the battery state-of-charge (SoC) and the physical constraints of the different energy conversion devices. During the charge-sustaining mode, the algorithm seems to try to operate the engine at its minimum BSFC line as much as possible. Assuming that this is the only modeled control strategy, the question here is about the representativeness of this control strategy.

EPA Response: *EPA constructed the P2 model based on the operation of a popular and well-performing vehicle in the fleet (in this case a Hyundai Sonata). The engine control strategy in ALPHA demonstrates a good match with test data from the vehicle operating on the regulatory cycles. Although we recognize there are a wide variety of operational strategies in the fleet, we believe over regulatory cycles this strategy would produce energy and fuel consumption results that are reasonably representative of a wide swath of the present and future fleet.*

B. Other more complex and efficient controllers, such as the ECMS (equivalent consumption minimizing strategy) based on Pontryagin's Maximum Principal optimization techniques, can reduce total fuel and energy consumption, and several vehicle manufacturers have considered it. While on the other hand, other simpler heuristics rule-based controllers can also be implemented. In addition, the domain of hybrid vehicle controllers has been going beyond the traditional optimization-based or rule-based methods as more advanced neural network- and machine learning-based control strategies are under continuous development. So, the question here is mainly about the representativeness of the adopted control strategy.

EPA Response: *EPA has chosen to incorporate vehicle components and control strategies that already exist within the current fleet and are representative of the performance of a broad range of vehicles as part of our updates to ALPHA. At this time, we are not implementing hybrid control strategies that have not been brought to production. However, for future development of ALPHA we may consider evaluating more efficient algorithms as part of our ongoing research programs.*

C. In the generated results file in MATLAB workspace, there is a mention of a "s_factor," which seems drive cycle dependent. It is unclear why this factor is defined and how it is used in the model. This question is raised here as the "s_factor" is a common notion in the academic literature regarding hybrid vehicles' control strategies which is defined as a conversion factor between fuel energy and battery energy.

EPA Response: *The S factor is used to correct the fuel consumption to a zero-change in battery SOC, using the method outlined in Appendix C of SAE procedure J1711 (Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles). In this way, the effective CO2 impact of charging or discharging the battery over the length of the cycle is included in the final tally. The S factor used is indeed cycle dependent; the values come from test data informing a draft (not yet finalized) update to the J1711 standard. Once the J1711 standard is updated, these values will be altered if necessary. An explanation of the definition and use of the S factor will be added to the documentation.*

D. The battery model is a resistance-capacitance (RC) equivalent circuit model that captures the dynamic battery voltage drop as a function of the battery's main state variables, such as SoC and temperature. RC equivalent circuit models are proven to be robust models and widely used in battery modeling for vehicle energy assessment. The battery model also includes a thermal sub-model where the battery temperature and different heat transfer phenomena are estimated. The battery's internal heat generation due to the exothermic chemical reactions is well presented. The battery heat exchange with its surroundings, either with the ambient or the cooling system, seemed to be simplified in a single parameter: the battery pack's total conductance. It is unclear to us what battery cooling technologies are considered and to what extent this approach can consider different cooling techniques, such as active/passive air or liquid cooling. While this issue might not be a game changer in hybrid powertrains, the battery temperature is more critical on pure electric powertrains, given the size of the battery, which would affect the battery performance and total energy consumption. In addition, the battery efficiency seems to be quite high (96.9% on UDDS_1, 97.7% on UDDS_2, 98.7% on highway cycle, 91.8% on US06_1, 97.3% on US06_2).

EPA Response: *The battery pack parameters (Open Circuit Voltage – OCV, and Series Internal Resistance – R) were tuned to match the terminal voltage and current response of the battery pack data collected on chassis dynamometer during the drive cycle testing. This ensured the modeled charge flowing on and out of the battery during dynamometer testing correlated with the test data and we found the battery losses and battery efficiency also corresponded with test data. For example, the internal resistance of the BEV battery pack – and thus the expected losses – is very similar to published data from a VW iD.3 (see Nikolaos Wassiliadis, Matthias Steinsträter, et al., "Quantifying the state of the art of electric powertrains in battery electric vehicles: Range, efficiency, and lifetime from component to system level of the Volkswagen ID.3," eTransportation, Volume 12, May 2022, 100167).*

Beyond the cycle efficiency numbers, there are additional battery losses associated with battery charging from an AC power source. As these charging losses do not occur during the dynamometer operation, they are not included in the quoted battery efficiency number. Instead, they are postprocessed within ALPHA using a nominal "charging efficiency" factor which includes both losses within the charging system and losses in the battery during charging. This "charging efficiency" factor is the ratio of DC energy used during the dynamometer test to AC energy supplied to the vehicle, and is set to 0.90, based on average values recorded during multicycle tests of BEVs.

E. The electric machine model is mainly data-driven, summarized in dynamic look-up tables focusing on the maximum torque curves and energy conversion efficiency. It is unclear whether the model differentiates between continuous and peak torque. The electric machine losses seem to be quite high (23% on UDDS_1, 29% on UDDS_2, 15% on highway cycle, 26% on US06_1, 14% on US06_2). It is not clear if these are losses during both propulsion and regenerative braking modes.

EPA Response: *Regarding continuous versus peak torque, the dynamic lookup tables within ALPHA are capable of varying available torque based on a thermal model or other criteria. For the included demo simulations, a static map was used. This is an area where further development is planned.*

The losses quoted are not the throughput losses (i.e., 1 – efficiency). Rather, they are the percentage of propulsion energy that is lost within the electric drive unit (specifically for the BEV, this would be the percentage lost with respect to the total battery energy used during the cycle). The electric drive unit includes the emotor, power electronics, and gearing, and the electric machine losses quoted reflect losses in all three components. The efficiency of the EDU in the BEV model supplied to the peer reviewers tends to be in the range of 87% - 92% when operating over the EPA regulatory cycles.

EPA notes the electric machine efficiency was not reported in any output file which would be a helpful quantity to provide ALPHA users. Therefore, EPA will add columns to the "results.csv" file for future public releases to allow easier review of key simulation run parameters (e.g., emotor efficiency, engine efficiency, battery efficiency, etc.). In addition, EPA notes the demo files provided for the peer review had the output verbosity set to 1, which produced a fairly limited "results.csv". Higher verbosity levels will automatically include additional parameters in the results file. EPA plans to insert comments into the sample scripts to better alert the user that additional data can be output.

F. The different transmission systems and the engine are developed with high fidelity. The gear-shifting strategy behaved as expected for some sample runs. The transmission system model is highly complex, which raises the concern of data availability for model calibration for different vehicles.

EPA Response: *The ALPHA shifting algorithm was developed to replicate actual vehicle behavior. (See: Newman, K., Kargul, J., and Barba, D. (2015) "Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation," SAE Int. J. Engines 8(3):2015, doi:10.4271/2015-01-1142.) We have used the shifting algorithm to validate multiple conventional vehicles and have found there is a reasonably good match between ALPHA shift results and shifting over the regulatory cycles with vehicles whose transmissions are calibrated to emphasize fuel economy.*

G. The powertrain auxiliaries, such as the air conditioning (AC) unit, fan, pump, and other electric auxiliaries, seemed to be modeled simply as constant power demand from the battery or torque demand from the engine. While this simplification is acceptable for most auxiliaries, such an approach can misestimate the AC/heating unit energy consumption, which is highly sensitive to dynamic operating conditions such as external temperature and trip duration. Detailed vehicle cabin thermal and AC/heating models would enhance the model capabilities to model the AC energy consumption providing a more accurate estimation of the vehicle's fuel economy/energy efficiency. Although the user can still input different auxiliary consumption in kW to mimic additional heating and cooling needs, quantifying such metric is a complex process that may incur inaccuracies. Thus, modeling such behavior is quite essential.

The academic literature has grown rich recently with modeling techniques to integrate vehicle powertrain and vehicle cabin thermal modeling into a single platform. Some examples of such literature are:

- Marcosa, D., Pinob, F.J, Bordonsa, C., Guerrab, J.J., "The development and validation of a thermal model for the cabin of a vehicle" Applied Thermal Engineering, https://doi.org/10.1016/j.applthermaleng.2014.02.054.
- Doyle, A., Muneer, T., "Energy consumption and modeling of the climate control system in the electric vehicle". Energy Exploration & Exploitation, https://doi.org/10.1177/01445987188064.

***EPA Response:** ALPHA is used to simulate room-temperature regulatory cycles performed on a chassis dynamometer (with the HVAC system turned off). In this case, there are no losses due to HVAC loads, although ALPHA does provide a tunable parameter to represent that loading if the user wishes. For the remaining losses, rather than individually modeling them, the effects of all accessory losses (including energy used for battery thermal management) are combined into one generic accessory load, whose value is set based on vehicle test data.*

However, EPA agrees that higher fidelity modeling of these losses would enhance ALPHA's capability to perform other types of simulations, and we are planning to develop HVAC and thermal control modeling capability in ALPHA (especially for BEVs) to support future laboratory research programs. We thank the reviewer for the specific literature recommendations.

H. Regarding the drive cycles, it appears that the US06 drive cycle is split into two phases, with the first phase incorporating the hard accelerations and the second phase incorporating the high speeds. We recommend adding a combined US06 audit.

***EPA Response:** The US06 drive cycle is customarily divided into "city" and "highway" phases as described by the reviewer. EPA feels there is a benefit in analyzing the two phases independently (for both the US06 and UDDS) and thus report them as such. A combined "EPA_UDDS & EPA_HWFET & EPA_US06 audit" is already included to allow a quick visual verification of 100% conservation of energy for the entire simulation run.*

I. The output file structure looks appropriate and complete. The model, however, lacks a master input file where the user can easily visualize all inputs. While this is understandable for a non-commercial model, a master input file would ease model validation and allow the user to conduct parametric studies more easily, which would help provide a more solid idea of the entire model's robustness.

***EPA Response:** The version of ALPHA provided to the reviewers contained only a few electrified model simulations configured via scripts and run independently. Using different scripts, ALPHA is capable of loading simulation parameters from a file either as a list of individual simulations or by using the full factorial expansion capability built into ALPHA. EPA plans to add an additional demo file to its public release of ALPHA to demonstrate this functionality.*

J. While a data-driven modeling approach is reasonable for vehicle fuel economy estimation, a significant amount of data must be collected or provided to parametrize the model correctly. Engine test benches and vehicle chassis dynamometers are well-developed standard practices for data collection for conventional powertrain technologies. However, it is unclear how data for batteries and electric machines were developed and the extent to which such data collection methods are well developed. While this review covers the modeling approach in general, clarifying the electric components' data collection approaches via proper documentation is essential for the user to understand the potential limitations of the model.

EPA Response: *EPA agrees that robust data collection to sufficiently represent the operation of components is essential. To model the behavior of electric machines, EPA uses emotor test data from suppliers, contractors, and other national laboratories. These data are collected from electric components using dynamometers, with methodologies similar to those used in engine testing. EPA independently evaluates the data to ensure the resulting ALPHA input maps reflect physically reasonable component performance.*

Data on battery performance are developed using widely recognized battery models whose parameters are then tuned so the current and voltage response match test data. For example, the BEV battery model was developed using published data from a VW iD.3 (see Nikolaos Wassiliadis, Matthias Steinsträter, et al., "Quantifying the state of the art of electric powertrains in battery electric vehicles: Range, efficiency, and lifetime from component to system level of the Volkswagen ID.3," eTransportation, Volume 12, May 2022, 100167).

EPA also agrees that explaining data collection and properly documenting the processes for obtaining electric component data is essential for a robust, transparent modelling process. We are documenting the electric component data used in ALPHA modeling and will be publishing this information on the EPA web site in conjunction with the rulemaking. Users of ALPHA can easily substitute their own emotor efficiency maps into ALPHA if they wish, without altering the underlying vehicle control strategy.

Question 3: Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?

Peer Reviewer: Sujit Das

A. The ALPHA model is a MATLAB/Simulink based full vehicle computer simulation model capable of analyzing various vehicle types combined with different powertrain technologies. Although both current and future advanced vehicle technologies can be explored by defining appropriate parameters in five major EV component files but requires a fairly knowledgeable of the specific MATLAB version (e.g., 2022a for the review version) to ensure robust and expeditious program execution.

EPA Response: *EPA agrees with the reviewer that exploring the full capabilities of ALPHA requires a fair amount of knowledge of MATLAB. ALPHA 3.0 was developed using MATLAB 2020a and should be compatible with subsequent versions of MATLAB. For regulatory purposes, we provide pre-populated input files so stakeholders can replicate EPA's analyses. Independent analyses which involve explorations of various parameters can be accomplished by stakeholders using ALPHA; however, this type of operation is best suited for users who are skilled in MATLAB and vehicle analysis. ALPHA does not have the extensive user support a similar commercial package would have.*

B. A specific simulation runtime is significantly high, more than 10 mins. without providing any indication to the user progress made so far. A user-friendly front end useful for an expeditious sensitivity analysis of key input parameters.

EPA Response: *There are a few factors driving the high run time for simulations. The provided demo cases were all set up using the REVS_log_all logging. This logs every signal in the model and requires a significant amount of memory. Additionally, whenever ALPHA reconfigures* *(changing powertrains or component models) it must be recompiled causing the first simulation to require additional time. Had the simulations instead swept parameters such as vehicle mass that do not require recompilation, subsequent simulations would have run significantly faster. In larger batch simulations, where a limited set of signals is logged, runtimes are generally under 30 seconds for each simulation.*

Regarding a progress display, there is a disconnect between MATLAB and Simulink, where once the Simulation is requested, feedback is not generated until the simulation is completed. For batch simulations there is a progress display that updates after each simulation. Considering the included demos only include one or two long running cases this functionality was probably not visible to the user.

EPA thanks the reviewer for the suggestion of a graphical front end. Given the flexibility of ALPHA, a user interface covering all features would probably be confusing, but a simplified version could help new users get acclimated, and EPA will consider implementing such a feature.

Peer Reviewer: Shawn Midland-Mohler

A. Overall, the modeling approach used seems appropriate to the technical goals. The fidelity selected provides fast execution. This does have drawbacks as it is heavily reliant on experimental maps as input. As outlined in a previous comment, the use of relatively simple control algorithms rather than techniques that have some manner of optimal control is a weakness. Adding this could result in slower execution time, however, it would likely result in better results with less overall run time for the user as it would require less runs to calibrate and adjust the control.

EPA Response: *The models within ALPHA are calibrated to replicate the performance of specific vehicles in the fleet which have been tuned by the manufacturer. The use of input maps and control algorithms measured/observed in the testing of representative vehicles grounds our ALPHA control algorithms in reality. These are simple in part due to the purposeful replication of the narrow vehicle operating conditions of hot start EPA regulatory cycles (e.g., room temperature, no HVAC, warmed up operation, etc.). Although the models within ALPHA could be re-tuned to increase their control strategy flexibility and scope (which might be valuable to some users), EPA does not have the need to do so in support of its current regulatory work.*

Peer Reviewer: ICCT

A. It is not possible to provide a solid opinion about engineering judgment and model robustness without a thorough comparison between simulation results and real-world testing data at the component level and vehicle level. The peer reviewers asked EPA if ALPHA has been validated against real-world results. EPA answered that each sub-model had been thoroughly validated against data collected from vehicle dynamometer testing internally and externally, where the tested vehicle behavior was reproduced with the model. The general approach of the model validation process, as shared by EPA, sounds reasonable and comprehensive. The modeling run demos provided by EPA demonstrate good agreement between simulation results and real-world data, but a more robust assessment is beyond the scope of our review.

EPA Response: *EPA thanks the reviewer for this comment and acknowledges that a robust,* *deep-dive assessment of model fidelity through the comparison of simulation results and real-world testing data is a time-consuming task. We appreciate the reviewer's expertise and observations on the importance of using real-world vehicle data to improving model robustness.*

B. One important point to mention is the impact of the simulation step size on the simulation error. While it is understood that a smaller step size would yield a lower error at the expense of higher computation resources, it is unclear how the simulation step size is set and what simulation error is considered acceptable.

EPA Response: *EPA agrees with the reviewer that simulation step size and resultant error is important to robust simulation. We feel we set an appropriate step size (100 Hz) and our energy audits (documented in the "console.txt" files) confirms that energy is being conserved within the model during simulations. Additionally, simulation step size is a parameter which can be changed by the user if desired.*

Question 4: Does the ALPHA model generate clear, complete, and accurate output/results (CO2 emissions, or fuel efficiency output file)?

Peer Reviewer: Sujit Das

A. The output Excel file is fairly simple with summary results of fuel economy (MPGe and Whr/mile). Fuel efficiency output file is detailed and clear with both Phase and Weighted aggregate results of energy economy, efficiency, and consumption by drive cycles. Energy Audit report by the drive cycle is fairly detailed in terms of energy balance at the gross level and by major EV components.

Energy consumed by Accessories has been accounted as the sum of Generic and DCDC Converter Losses. Fuel consumed (grams and gallons) including CO2 emissions for conventional vehicles are reported under Phase Results by drive cycles.

The simulated AC usage in UDDS and HWFET drive cycle results of a 2019 Tesla Model S Standard Range compared well (within less than 2%) with EPA certification values.

EPA Response: *Thank you for the comment; EPA agrees.*

Peer Reviewer: Shawn Midland-Mohler

For this charge question, the output will be considered the log file, the console output file, the results file, and the figures that are generated from the model run.

Clear Output/Results:

A. Log File: Overall, this was reasonably well organized. See comments below on some items that led to some confusion.

EPA Response: *Thank you for the comment; EPA agrees.*

B. Console Output: This was clear. Given the tabular nature of the data, it would be helpful to output this as a .csv or use the Report Generator capability in MATLAB to give it structure as a pdf. I can see users having to do cutting and pasting to use this data for whatever their purpose was.

EPA Response: *The console output is primarily intended to be used for diagnostic purposes* *to confirm conservation of energy. The values displayed in the console output's energy audit are accessible in the workspace and thus could be manually added in the CSV result files. Developing scripts to add any desired columns for the energy audit will be considered for future development.*

C. Results File: This was clear, but the horizontal format is not what I would have preferred. It seems like it would be more readable as a .csv in a spreadsheet app if it were arranged vertically.

EPA Response: *The peer reviewers were supplied with individual example runs for each electrified technology. However, ALPHA is typically run in a batch mode with either multiple vehicles or multiple permutations of parameter values, and the output file contains results from all vehicle simulations. In these cases, with dozens or hundreds of vehicle simulation outputs, the horizontal .csv format lends itself more easily to post-processing analysis and manipulation.*

D. Figures: Many of the figures did not contain proper units for some of the axes. I was able to infer the likely units but that is clearly not good practice. Given that the figures are only generated upon run, I would have appreciated them being saved or, at a minimum, written into a pdf file and logged with the above files.

EPA Response: *EPA agrees with the reviewer that properly labeling figure axes is desirable. We will update the scripts in ALPHA to ensure axes contain units. For the provided sample simulation scripts, the plot generation was done at the end of the script, outside of the batch simulation operation. To generate and organize plots for each simulation case would require moving the plot generation into a case post-processing script. Calling the DOR plot scripts with the MATLAB publish command can be used to send the resulting figures to a pdf. EPA agrees this is a useful feature and will work on developing the postprocessing script and a demo showcasing its usage.*

Complete Output/Results:

E. Log File: The log files that I inspected did not seem to fully be populated with data or I may have been misunderstanding the intent. In the "Configuration Keys" section there were many entries without values, for instance the A, B, and C coefficients did not list values. I expected these to be the values that were used to generate the results. There were many other areas where this was the case.

EPA Response: *The "Configuration Keys" section of the log files are intended to document how the batch was configured, and not to document the individual simulations. Regarding the ABC coefficients not having values, those configuration keys are intended to override values that would otherwise be set via the vehicle param files. For a simple simulation, most model parameters are set in the various component parameter files rather than in the log file, and the blank configuration keys represent those parameters whose values default to the values in the vehicle param files. The documentation can be revised to better clarify the use of the configuration keys and the distinction between values set in the log file and those set in the vehicle param files.*

F. Console Output: The console output contained a good summary of overall cycle energy flows.

EPA Response: *Thank you for the comments; EPA agrees.*

G. Results File: The results file contains an effective summary of each cycle and the overall composite of the cycles run from an energy perspective.

EPA Response: *Thank you for the comments; EPA agrees.*

H. Figures: The set of figures shown was satisfactory. Obviously, a person can generate their own. A concern is that I did not see that the data from a simulation was logged. I would prefer to have that option to avoid having to rerun a simulation. I was able to locate the time series output in the "model_data" structure. I assumed that this was the model parameters based on the "data" label – instead it was the output. I think "model_output" would have been a more appropriate name or something even more descriptive.

EPA Response: *ALPHA contains a couple different mechanisms for saving the simulation data which are more thoroughly described in the documentation and configured within the sim_batch object. If retain_output_workspace is set to "true", then simulation data is saved in memory and is accessible with the extract_workspace method for each simulation case. Alternatively, data can be logged to a mat file by setting save_output_workspace to "true." The "model_data" nomenclature is carried over from our model validation activities where it is compared to a similarly organized "test_data" object. The comment is appreciated and will be a topic for further discussion by the developers.*

Accurate Output/Results:

I. Overall, the accuracy is difficult to assess because the models provided are only representative of classes of vehicles and no direct comparison data is provided. Upon request by the reviewers, the EPA provided simulation results that were representative for a 2019 production EV. The results cycle-based results agreed very well with the experimental results provided. This demonstrates that it can generate valid results.

EPA Response: *EPA agrees ALPHA can generate valid results and acknowledges that a robust, deep-dive assessment of model fidelity through the comparison of simulation results and real-world testing data is a time-consuming task.*

J. Overall, the modeling approach is known to be able to predict cycle energy usage well under nominal conditions. Additional factors like HVAC loads and cold/hot weather performance can be challenging to model with the current fidelity of the models. I do not feel that is something that the model is expected to be able to do at this point, so this compromise is understood. To bring those factors into the model, additional systems need to be directly modeled or the resulting loads on the system need to be brought in via the existing accessory load and efficiency models. This typically requires detailed information on components/controls and/or experimental data that is often not easily obtained outside of OEMs.

EPA Response: *ALPHA simulates room-temperature regulatory cycles performed on a chassis dynamometer as a result, there are no losses due to HVAC loads. However, EPA agrees higher fidelity modeling of these losses would enhance ALPHA's capability and we are considering improving this modeling for future versions of ALPHA.*

Additional Comments/Questions:

K. It was not clear to me if there is a warning issued if the drive trace is violated. If not, this would need to be added because results when this occurs may not be valid.

EPA Response: *EPA agrees tracking drive trace violations is necessary. ALPHA does track drive trace violations (if any) and can report the percentage of time the simulation is outside the drive trace envelope. In the peer review outputs, this can be found in the console. EPA normally also indicates trace violations in the CSV results file. EPA will consider ways to make any trace violation more obvious in the simulation output files.*

L. It was not clear to me if there is a correction for SOC variation for non-plug-in hybrids.

EPA Response: *ALPHA accounts for the SOC variation by using an S factor to correct the fuel consumption to a zero-change in battery SOC. The method used is outlined in Appendix C of SAE procedure J1711 (Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles). EPA will update ALPHA documentation to note the use of the S factor to account for SOC variation.*

M. It was not clear to me in the structure of the model if the translational mass of the rotational components were factored appropriately. There was some discussion of this in the manual but without having time to really investigate this I could not be certain. I noted how the rotational inertia was carried forward in the model to be added into the overall mass where the vehicle inertial integrators were.

EPA Response: *The physics within ALPHA are simulated via torques and rotational inertias which are carried down through the powertrain to either a disconnection point, an open clutch for example, or the wheels. Within the tire model the torque is translated into force while the rotational inertia of upstream components is translated into an equivalent mass which can be added to the static mass of the vehicle. From these values the acceleration and speed can be computed. We agree the graphical nature of a Simulink model can make it difficult to determine whether the physics are represented properly. A more thorough description of these models has been included in some of our prior publications and could be included within the user documentation to clarify the matter. Concerns regarding conservation of energy was a primary reason the energy auditing was implemented, allowing the changes in stored energy to be vetted against the sum of the energy consumed by each of the component losses.*

N. In reviewing the model_data variable, I noted that the model_data.controls part of the structure was not populated with data. There were variables there in the EV and PS model, but they did not contain data vectors.

EPA Response: *Controls is an area where EPA has not often used the model_data variable during development, preferring instead to use the signals in datalog.controls which are more powertrain specific. The model_data variable is constructed from class_test_data which was originally developed to provide a standard structure into which data from vehicle testing could be loaded and is integral to the DOR functionality. ALPHA only generates a subset of the signals class_test_data is capable of loading; thus, many variables are left unused.*

Peer Reviewer: ICCT

A. The ALPHA model generates automatic plots describing the physical behavior of the main powertrain components, in addition to a console text file summarizing the energy consumption, fuel economy, and CO2 emissions. We recommend the following to make the results file more readable:

- The accessory's energy consumption doesn't show the share of each component (fan, AC, pump, etc.). These are aggregated under one value. Although the generated results files contain placeholders for these accessories, they show a value of zero.

  EPA Response: *For these variables, users have the option of defining energy consumption for each component individually or defining the total energy consumption for all accessories. For the peer review, the total energy consumption was defined as a single generic loss, whose value is derived from chassis dynamometer test data, without defining the breakdown into individual accessory systems. The zero values represent placeholders for the individual quantities not itemized.*

- There is no mention of the battery's thermal needs as an accessory consumption. Is battery cooling/heating consumption considered part of the battery losses? It is worth documenting how the model handles battery thermal needs.

  EPA Response: *EPA agrees that documenting how ALPHA incorporates battery thermal management losses is preferred. The accessories are modeled in ALPHA as a single generic loss, whose value is derived from chassis dynamometer test data. However, EPA plans to begin developing ALPHA's battery thermal management modeling (especially for BEVs) to support potential future regulations.*

- The results file mentions "kinetic energy" as a potential energy source in addition to fuel and stored energy. It is unclear whether this refers to brake energy recovery or another indicator.

  EPA Response: *Kinetic energy mentioned in the file refers to the kinetic energy of the vehicle, and therefore the amount of energy available for recovery when braking. EPA will clarify this term in the documentation.*

- The fuel energy could be further detailed into direct flow to the driveline or energy flow from the engine to the battery, depending on the powertrain architecture. This can provide a clearer idea of the control strategy under different drive cycles, operating conditions, and system boundary conditions.

  EPA Response: *ALPHA does track electrical energy into and out of the battery which, like fuel energy flow, can be used to provide an idea of the control strategy. The advantage of tracking electrical energy is that it directly coincides with a measurable quantity in the vehicle, as opposed to fuel split which must be calculated. However, EPA will also consider incorporating a similar fuel energy calculation.*

B. In the model, it is mentioned that the final drive efficiency is already included in the electric drive unit. This is probably why the final drive losses are always set to zero in the results report. However, the final drive is separate from the electric motor, and combining their efficiencies limits the model's flexibility. We recommend fixing this issue.

   EPA Response: *ALPHA has the option of modeling the final drive as part of the motor (in which case the separate final drive block losses are zero) or separately in the final drive block. For the peer review, the e-machine map used for the BEV model was based on test* *data from an entire electric drive unit (EDU), which included the gearing and the gearing losses. However, if the user wishes to incorporate an e-machine which does not include gearing, the gearing losses and ratio can be defined within the final drive.*

Question 5: Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?

Peer Reviewer: Sujit Das

A. Detailed sixty complementary graphical output files as a function of drive cycle time to the three summary output files provided would have useful for the evaluation of the model functioning. Unless an expert MATLAB/Simulink user, it is not intuitive to track down the logical flow of summary final results from its initial parameter values used in underlying equations.

EPA Response: *EPA agrees the overall process from input parameters, simulation configuration, simulation, and output processing can be confusing in part due to the effort to make the simulation process in ALPHA highly configurable. Additional documentation explaining the process from a higher level will be added in the future.*

Peer Reviewer: Shawn Midland-Mohler

A. I provided some specific recommendations in the above section. I do not have any additional comments to provide.

EPA Response: *EPA thanks the reviewer for the detailed and thoughtful comments above.*

Peer Reviewer: ICCT

A. Hybrid and plug-in hybrid vehicles' controllers (energy management strategy) are rigid and developed based on specific strategies and algorithms. Providing the option to simulate several hybrid control strategies as part of the batch simulation runs would be more comprehensive and may cover a broader range of vehicles.

EPA Response: *The models within ALPHA are calibrated to replicate the performance of specific vehicles in the fleet which have been tuned by the manufacturer. Although the models within ALPHA can be re-tuned by EPA or stakeholders, for its current regulatory modeling EPA does not need to replicate the wide array of control algorithms in the fleet. Please also see EPA's response to Charge Question 3, Shawn Midland-Mohler, comment A.*

B. A bottom-up approach is recommended to estimate the vehicle weight. Estimating the components' weights and aggregating these weights to calculate the total vehicle weight can provide a more accurate estimation of the impact of different technology choices, especially different battery, and electric motor sizes.

EPA Response: *ALPHA is used to simulate vehicle behavior during chassis dynamometer testing which is performed using the equivalent test weight (ETW) provided by the manufacturer. EPA agrees with the reviewer that estimating the effect on weight of various technology choices can be useful, but that analysis is beyond the scope of ALPHA.*

C. A master input file can ease the execution of parametric studies and help validate the model's behavior and the component and system levels.

EPA Response: *The version of ALPHA provided to the reviewers contained only a few electrified model simulations which were run independently. However, ALPHA also includes a batch processing script where all inputs can be listed and multiple simulations (e.g., parametric studies as suggested by the reviewer) with different inputs can be simulated together with both input and output parameters collected in a single file.*

D. Improve the model documentation with explicit modeling assumptions, especially regarding hybrid controllers.

EPA Response: *EPA agrees with the reviewer that improving the documentation for ALPHA would aid users, and specifically that an expanded description of hybrid controllers would be beneficial. We will work to implement this in the ALPHA documentation. Please also see EPA's response to Charge Question 2, Shawn-Midland-Mohler, comment E.*

E. It is essential to provide insights into the representativeness of the core data used to develop these models. It is not entirely clear when these data were collected, how relevant they are today, and how relevant they will be in the long term.

EPA Response: *EPA agrees with the reviewer that explaining data collection and relevance, and properly documenting the processes for obtaining electric component data is essential for a robust, transparent modelling process. These data were collected using methods similar to those used in engine testing which is described in detail on our website: https://www.epa.gov/vehicle-and-fuel-emissions-testing/benchmarking-advanced-low-emission-light-duty-vehicle-technology. EPA independently evaluates the data to ensure the resulting ALPHA input maps reflected physically reasonable component performance as described on our website: https://www.epa.gov/vehicle-and-fuel-emissions-testing/combining-data-complete-engine-alpha-maps. EPA is in the process of documenting the electric component data used in ALPHA modeling and will be publishing all the information on a new EPA web page dedicated to electric components. However, users of ALPHA can easily substitute their own emotor efficiency maps into ALPHA if they choose without altering the underlying vehicle control strategy.*

ADDITIONAL OVERALL COMMENTS PROVIDED (NOT CHARGE QUESTION-SPECIFIC)

Peer Reviewer: Sujit Das

A. A different detailed simulation model primarily for electrified vehicles needs to be developed with a focus on life cycle CO2 emissions instead of tailpipe emissions simulated by ALPHA.

EPA Response: *ALPHA is intended to simulate vehicle performance on regulatory cycles performed on a dynamometer. A life cycle analysis for CO2 would, by definition, need to incorporate factors and assumptions beyond vehicle dynamometer behavior and is beyond the scope of ALPHA.*

B. Any comparative analysis with the similar forward-looking, full vehicle computer simulation model such as AUTONOMIE used by U.S. Department of Energy will be useful towards the model validation.

EPA Response: *EPA has compared the ALPHA simulation of a conventional vehicle to an Autonomie simulation of the same vehicle. We concluded that given the same inputs, not only were the CO2 emissions very similar, but the second-by-second vehicle performance* *was very similar as well. EPA will consider different approaches for providing such analyses to the public for consideration.*

C. It is critical that the level of accuracy of vehicle performance results obtained from a simplistic model such as ALPHA be frequently demonstrated and documented to meet the stringent requirements of any Federal regulation such as CAFE in this case.

EPA Response: *EPA agrees documenting ALPHA and demonstrating its accuracy is important. In support of this approach, EPA has spent considerable time and effort producing publicly available ALPHA documentation in publications such as the Draft Technical Assessment Report (TAR), benchmarking data, key ALPHA input file descriptions, key ALPHA result outputs, and technical papers and presentations. Many of these describe ALPHA validations against detailed data captured on the dynamometer. However, an important factor to consider is that ALPHA is EPA's tool internally developed and used to estimate future CO2 emissions and is not a regulation compliance tool.*

Peer Reviewer: Shawn Midland-Mohler

A. In browsing the model documentation, it was very heavy on the programming structure of the model and very light on the actual modeling approach. For instance, the only model that seemed to describe in any detail was the vehicle loss and inertia model. There was very little insight provided into other plant models or the control models. For others to adopt this methodology, these details need to be readily available to users. As it is now, a potential user is left to interpret the intent of the model from the structure of the code. This is possible, but it leaves lots of questions and for it to be widely adopted would need to have more information provided.

EPA Response: *EPA agrees documentation for ALPHA could always be improved and will work to do so within our resource constraints. We thank the reviewer for the specific suggestion of providing more detail about other plant and control models. Some additional model details have been provided in other publications which will be integrated into the manual. The initial purpose of the provided documentation was to establish a consistent framework for continued ALPHA development which includes a heavy connection with the program structure. Please also see EPA's response to Charge Question 2, Shawn-Midland-Mohler, comment E.*

Peer Reviewer: ICCT

A. The review process of the ALPHA model considered both the provided MATLAB/Simulink scripts and models and the accompanying documentation. Generally, the different battery-electric and hybrid powertrain models are developed based on solid methodologies that capture state-of- the-art technologies with proper modeling techniques. The modeling approach is thorough and presents a comprehensive energy analysis of the different powertrain physical domains, where the sub-systems' interactions are clearly defined and well established. The core of the models mainly relies on a data-driven approach, where the physical behavior of the main powertrain components, such as the battery, electric machine, engines, etc., is captured using multidimensional data sets. This simplification is understandable at the powertrain system level, as simulating the dynamic physical behavior of every component would be beyond the scope of this model.

The structure of the model is modular, allowing a standardized modeling and simulation environment for all powertrain technologies based on a common model core, as presented in the different libraries. The model includes a detailed set of controllers that dictate the behavior of the powertrain and permit communication among its components. The model architecture is well-organized and self-descriptive, helping the user navigate easily and making it less prone to logical and syntax errors. Finally, the model results are communicated through an output file summarizing the main key performance indicators at the system level, in addition to detailed output files describing the different components' behavior.

EPA Response: *Thank you for the comments; EPA agrees.*

B. Nonetheless, some assumptions at the component model and control levels are not clearly presented and require more clarification. These are discussed in more detail in question 2 in the responses to the charge questions.

EPA Response: *Controls and components for the electrified models were based on the operation of specific popular and well-performing vehicles in the fleet (for example, the P2 model was based on a Hyundai Sonata). The engine control strategy in ALPHA demonstrates a good match with test data from these vehicles. Although we recognize there are a wide variety of operational strategies in the fleet, we believe our approach produces energy and fuel consumption results that are reasonably representative of a wide swath of the present and future fleets.*

C. Finally, the provided documentation falls short of what would have been needed to develop a high-level understanding of the model structure and its input-output framework. The lack of proper documentation forces the user to dig deep into the code and structure of the models to understand the model's inner workings. While it is understood that such documentation is not meant for commercial use, a more organized summary of some critical assumptions would have been appreciated. This also renders more transparency to the overall data-driven modeling approach.

EPA Response: *EPA agrees documentation for ALPHA could always be improved and will continue work to do so. Descriptions of the electrified vehicle architectures modeled will be included in our Regulatory Impact Analysis and the validation of these models will be described in a future SAE paper. As these materials develop, we will also add more to the ALPHA documentation to describe how the variables get passed into and out of Simulink for the actual simulations.*

Appendix A: Comments by Reviewer (Unedited)

Comments by Sujit Das

CHARGE QUESTION	COMMENTS
1. Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?	Four major types of electrified vehicles have been considered in ALPHA and it is appropriate that the ALPHA simulations of two most important vehicle types (i.e., BEV and PowerSplit HEV) in the near-term have been selected for the peer review. Of the electrified vehicles, U.S. DOE/EIA projects new BEV sales increase faster than any other type of battery-powered vehicles, both electric hybrid and 300-mille electric vehicles reaching at ~ 1.2 million/year and both BEVs and PHEVs combined would account for 13% of total LDV sales in 2050, according to the AEO2022 reference case. As ALPHA model has been primarily created to evaluate the GHG emissions of ICE Light-Duty vehicles, it is less appropriate to evaluate alternative pure EV technologies. It is also to include other specific electric vehicle types, i.e., sedan, SUV, CUV, and pickup in the future model updates.
2. What is the appropriateness and completeness of the overall model structure and its components, such as: o The breadth of component models/technologies compared to the current/future light-duty fleet o The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component. o The input and output structures and how they interface with the model to obtain the expected result, i.e.,	ALPHA model is fairly straight forward tool only for an experienced MATLAB user for understanding vehicle behavior, greenhouse gas emissions and the effectiveness of various powertrain technologies of current and future vehicles by appropriately changing input values in five major vehicle parameter files. Parameter files are organized at the level of five major EV components, i.e., Base (Driver and Controls), Vehicle, Electrical, Accessory, and Transmission for running a desired EV technology. Battery and the electric machine are a part of the Electrical component. The ALPHA model is currently limited to CO_2 emissions for five different EPA driving cycles including custom driving cycles based on test fuel properties and vehicle fuel consumption. An assessment of the underlying model equations and/or physical principles couldn't be made as they were limited to the original Simulink code without any appropriate

CHARGE QUESTION	COMMENTS
fuel/energy consumption and CO_2 over the given driving cycles. o The use of default or dynamically generated values to create reasonable models from limited data sets.	model documentation available including the limited peer review time. ALPHA model 0.2.0 documentation is an excellent resource for a MATLAB model user in terms of the contents of various files, but no description of types of equations including the source and validation of the equation parameter values used. A Data Dictionary of variables used in the model would be useful for better understanding of a novice user. The model is completely input data driven, which need to be collected by either engine or chassis dynamometer testing by specific vehicle system technology case. The model application is thereby limited to the extent of validated data availability. The overall model performance is dictated by calibration of numerous technology-specific parameters used to determine final vehicle fuel economy and CO_2 emissions for various vehicle drive cycles. The input structure is defined by five major component MATLAB files, in which the input parameter values can be changed for the simulation of new technologies. The expected results of fuel/energy consumption and CO_2 over the given driving cycles for the two vehicle types reviewed were reasonable. For PS HEV HWFET drive cycle, CO_2 emissions was estimated to be 4%-21% higher than for the UDDS cycle. The use of default or dynamically generated values could only be assessed by the final summary output results. A documentation on the approach and the sources used for the input parameter values would be useful for the model user to develop or any new technologies.
3. Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?	The ALPHA model is a MATLAB/Simulink based full vehicle computer simulation model capable of analyzing various vehicle types combined with different powertrain technologies. Although both current and future advanced vehicle technologies can be explored by defining appropriate parameters in five major EV component files but

CHARGE QUESTION	COMMENTS
	requires a fairly knowledgeable of the specific MATLAB version (e.g., 2022a for the review version) to ensure robust and expeditious program execution. A specific simulation runtime is significantly high, more than 10 mins. without providing any indication to the user progress made so far. A user-friendly front end useful for an expeditious sensitivity analysis of key input parameters.
4. Does the ALPHA model generate clear, complete, and accurate output/results (CO_2 emissions or fuel efficiency output file)?	The output Excel file is fairly simple with summary results of fuel economy (MPGe and Whr/mile). Fuel efficiency output file is detailed and clear with both Phase and Weighted aggregate results of energy economy, efficiency, and consumption by drive cycles. Energy Audit report by the drive cycle is fairly detailed in terms of energy balance at the gross level and by major EV components. Energy consumed by Accessories has been accounted as the sum of Generic and DCDC Converter Losses. Fuel consumed (grams and gallons) including CO_2 emissions for conventional vehicles are reported under Phase Results by drive cycles. The simulated AC usage in UDDS and HWFET drive cycle results of a 2019 Tesla Model S Standard Range compared well (within less than 2%) with EPA certification values.
5. Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?	Detailed sixty complementary graphical output files as a function of drive cycle time to the three summary output files provided would have useful for the evaluation of the model functioning. Unless an expert MATLAB/Simulink user, it is not intuitive to track down the logical flow of summary final results from its initial parameter values used in underlying equations.

ADDITIONAL OVERALL COMMENTS PROVIDED (NOT CHARGE QUESTION-SPECIFIC):
A different detailed simulation model primarily for electrified vehicles needs to be developed with a focus on life cycle CO2 emissions instead of tailpipe emissions simulated by ALPHA. Any comparative analysis with the similar forward-looking, full vehicle computer simulation model such as AUTONOMIE used by U.S. Department of Energy will be useful towards the model validation. It is critical that the level of accuracy of vehicle performance results obtained from a simplistic model such as ALPHA be frequently demonstrated and documented to meet the stringent requirements of any Federal regulation such as CAFE in this case.
ADDITIONAL COMMENTS BY SPECIFIC ELECTRIFIED VEHICLE MODEL
N/A

Comments by Dr. Shawn Midlam Mohler

CHARGE QUESTION	COMMENTS
1. Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?	The scope of the review is focused mainly on the BEV model and the PowerSplit HEV model with a secondary focus on the Strong P2 HEV and the Mild P0 HEV model. In all of these cases, the modeling approach is able to meet the goal of modeling energy consumption. I have concerns about the current state of the model with some concerns about how the control algorithms are implemented. A main concerns is regarding the likely adoption of this model or the utility for the intended purpose given the observation that: a) this class of model is already in the market; and b) the vehicles that this model focuses on (BEV, PowerSplit HEV, etc.) are available from many OEMs and, thus, there performance across many different vehicle classes is well-understood. The modeling approach used is typical to that used in industry and academia, thus, it is appropriate. However, the approach also does not lend itself to easy adoption outside of expert users. In general, people with sufficient expertise to modify this type of model and yield reasonable results likely already have existing models available to them. One of the stated goals is that ALPHA will gain wide acceptance in the light-duty vehicle automotive community, and I do not feel that is likely to occur in the current implementation. The model approach is very similar to that used in Autonomie which has the benefit of many years of development. A main feature in Autonomie that distinguishes it from ALPHA is the availability of a GUI for model creation, modification, and data analysis for users to exercises models. The ability to scale component models via a GUI, queue up different drive cycles, adjust control parameters, *etc*. seem to make it better suited for the intended purpose. Autonomie also has a more robust library of component options as well as more robust control algorithms.

CHARGE QUESTION	COMMENTS
	Because of the availability of tools like Autonomie, in-house tools, commercial tools like AVL Cruise, and even example models provided within MATLAB, it is unclear how ALPHA in its current form will meet the objectives. To be very clear, the technical approach of ALPHA seems to be sound. My concerns are that it is not providing a solution that is not already in the market with more established products. Furthermore, the marketplace now has a wide variety of electrified vehicles available and there is data associated with these vehicles in the public domain. Organizations have access to this data from their own vehicles as well as competitor assessments. From a planning perspective, it is not clear what a model like this is able to provide. In the area of BEVs, the increasing offering from many OEMs gives us the ability to reliably estimate things like range and energy consumption based on actual vehicle data. The core energy consumption of the energy storage system and traction motors which ALPHA focuses on is quite well understood and apparent from test data that is in the public domain via certification requirements. Aspects like HVAC load, battery cooling during fast charging, etc. which are areas which are more challenging which can significantly impact real-world energy usage and range are not well modeled in ALPHA or most models. None of the above should be taken as a comment on the modeling approach or skills of the developers. The approach seems to be typical of the class of models that others have deployed for this purpose. The main concern is if ALPHA will serve the intended purpose in terms of being impactful in the technical community. Given the availability of public domain data on these vehicles, the availability of internal data on their own vehicles to OEMs, the availability of competitor assessments, and the availability of other simulation products capable of the same type of analysis it is not clear how widely this tool will be used.

<table>
<tr><th>CHARGE QUESTION</th><th>COMMENTS</th></tr>
<tr><td>2. What is the appropriateness and completeness of the overall model structure and its components, such as:
o The breadth of component models/technologies compared to the current/future light-duty fleet
o The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.
o The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel/energy consumption and CO2 over the given driving cycles.
o The use of default or dynamically generated values to create reasonable models from limited data sets.</td><td><u>The breadth of component models/technologies compared to the current/future light-duty fleet:</u>

Overall, the model has the overall systems that one would expect for the stated goal. Given the importance of HVAC and battery thermal management to BEV and PHEV platforms, this is one area that is not well-developed in the model. The mechanical and electrical accessories are divided into four submodels, generic loss, power steering, air conditioning, and fan loss. In the BEV model, there was no energy usage associated with the engine fan, power steering, or air conditioning system. This could indeed be the case; however, the modeling approach is map-based and would require this information to be specified by the user. Given that the loads from these systems can cause significant reductions in in-use energy efficiency, higher fidelity of these models would certainly add to the capability of the model.

The control models deployed in the models reviewed also poses a challenge. As with any model of this class, a controller is necessary to manage the torque split and gear as well as other important vehicle functions. The quality of the control algorithm can have a major impact on the efficiency of the simulated vehicle – a great vehicle component design with a marginal control algorithm/calibration will perform marginally. There are optimization techniques that have been applied to this class of models to allow a more refined control to be deployed without excessive calibration by the user.

The control algorithm used for the Power Split vehicle was inspected which is in the PS_control.m function. The "working" part of the code consists of less than 100 lines of code and is what one would refer to as rule-based for the most part. There are comments included that say "% ::What is this?" and "% ???" which I can understand as a person who has done these things before – but also does not lend confidence in the maturity of the control algorithm provided. Given the importance of control</td></tr>
</table>

CHARGE QUESTION	COMMENTS
	algorithms for predicting the efficiency of vehicles it is critical that these be matured. **<u>The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.</u>** Overall, this is more or less an implementation of a force balance on the vehicle. The components are modeled via maps and the basic relationships between the components. No errors were noted in the summation of torques/forces that acted on the vehicle inertia. A model of this class relies on appropriate component maps and appropriate controls. Without a more rigorous look at these with comparison data it is not possible to provide a full assessment of this. When inspecting the driver commands (brake and accelerator) and high-level control inputs like gear shifts and torque commands, I did not find anything of concern. Depending on the underlying control algorithm and driver model, there can sometimes be high-frequency behaviors on these signals that are not representative of actual vehicle controls or driver behaviors. This was not noted in the model outputs reviewed. I was not able to find much documentation on the actual models used outside of the overall vehicle mass and loss model. This made it challenging to review the modeling approach as it needed to be interpreted from the model and input/output. **<u>The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel/energy consumption and CO2 over the given driving cycles.</u>** I provided very detailed comments on the output in response to the fourth Charge Question below. In this discussion, I will focus on the input structures. In the demo

CHARGE QUESTION	COMMENTS
	files provided, the input structure was clearly defined and using variants in the model appropriate subsystems were enabled. It was not clear to me if there was scaling that could be applied in the input structure – there did not appear to be. That is one aspect that is generally quite useful to be able to slightly adjust component sizes without having to generate new component data files. **The use of default or dynamically generated values to create reasonable models from limited data sets.** Compared to more mature projects like Autonomie, there are not many options. The capability is there, but I did not locate any library of models or the ability to scale them. Likewise, the control algorithms were very likely highly specific to the particular set of components they were calibrated to work with. I was not able to locate documentation on the nature of the controls but after inspecting the model and the input files it seemed to be very calibration-based.
3. Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?	Overall, the modeling approach used seems appropriate to the technical goals. The fidelity selected provides fast execution. This does have drawbacks as it is heavily reliant on experimental maps as input. As outlined in a previous comment, the use of relatively simple control algorithms rather than techniques that have some manner of optimal control is a weakness. Adding this could result in slower execution time, however, it would likely result in better results with less overall run time for the user as it would require less runs to calibrate and adjust the control.
4. Does the ALPHA model generate clear, complete, and accurate output/results (CO_2 emissions or fuel efficiency output file)?	For this charge question, the output will be considered the log file, the console output file, the results file, and the figures that are generated from the model run.

CHARGE QUESTION	COMMENTS
	<u>Clear Output/Results:</u> Log File: Overall, this was reasonably well organized. See comments below on some items that led to some confusion. Console Output: This was clear. Given the tabular nature of the data, it would be helpful to output this as a .csv or use the Report Generator capability in MATLAB to give it structure as a pdf. I can see users having to do cutting and pasting to use this data for whatever their purpose was. Results File: This was clear, but the horizontal format is not what I would have preferred. It seems like it would be more readable as a .csv in a spreadsheet app if it were arranged vertically. Figures: Many of the figures did not contain proper units for some of the axes. I was able to infer the likely units but that is clearly not good practice. Given that the figures are only generated upon run, I would have appreciated them being saved or, at a minimum, written into a pdf file and logged with the above files. <u>Complete Output/Results:</u> Log File: The log files that I inspected did not seem to fully be populated with data or I may have been misunderstanding the intent. In the "Configuration Keys" section there were many entries without values, for instance the A, B, and C coefficients did not list values. I expected these to be the values that were used to generate the results. There were many other areas where this was the case. Console Output: The console output contained a good summary of overall cycle energy flows. Results File: The results file contains an effective summary of each cycle and the overall composite of the cycles run from an energy perspective.

CHARGE QUESTION	COMMENTS
	Figures: The set of figures shown was satisfactory. Obviously, a person can generate their own. A concern is that I did not see that the data from a simulation was logged. I would prefer to have that option to avoid having to rerun a simulation. I was able to locate the time series output in the "model_data" structure. I assumed that this was the model parameters based on the "data" label – instead it was the output. I think "model_output" would have been a more appropriate name or something even more descriptive. <u>Accurate Output/Results:</u> Overall, the accuracy is difficult to assess because the models provided are only representative of classes of vehicles and no direct comparison data is provided. Upon request by the reviewers, the EPA provided simulation results that were representative for a 2019 production EV. The results cycle-based results agreed very well with the experimental results provided. This demonstrates that it can generate valid results. Overall, the modeling approach is known to be able to predict cycle energy usage well under nominal conditions. Additional factors like HVAC loads and cold/hot weather performance can be challenging to model with the current fidelity of the models. I do not feel that is something that the model is expected to be able to do at this point, so this compromise is understood. To bring those factors into the model, additional systems need to be directly modeled or the resulting loads on the system need to be brought in via the existing accessory load and efficiency models. This typically requires detailed information on components/controls and/or experimental data that is often not easily obtained outside of OEMs. Additional Comments/Questions:

CHARGE QUESTION	COMMENTS
	It was not clear to me if there is a warning issued if the drive trace is violated. If not, this would need to be added because results when this occurs may not be valid. It was not clear to me if there is a correction for SOC variation for non-plug-in hybrids. It was not clear to me in the structure of the model if the translational mass of the rotational components were factored appropriately. There was some discussion of this in the manual but without having time to really investigate this I could not be certain. I noted how the rotational inertia was carried forward in the model to be added into the overall mass where the vehicle inertial integrators were. In reviewing the model_data variable, I noted that the model_data.controls part of the structure was not populated with data. There were variables there in the EV and PS model, but they did not contain data vectors.
5. Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?	I provided some specific recommendations in the above section. I do not have any additional comments to provide.

ADDITIONAL OVERALL COMMENTS PROVIDED (NOT CHARGE QUESTION-SPECIFIC):

In browsing the model documentation, it was very heavy on the programming structure of the model and very light on the actual modeling approach. For instance, the only model that seemed to describe in any detail was the vehicle loss and inertia model. There was very little insight provided into other plant models or the control models. For others to adopt this methodology, these details need to be readily available to users. As it is now, a potential user is left to interpret the intent of the model from the structure of the code. This is possible, but it leaves lots of questions and for it to be widely adopted would need to have more information provided.

ADDITIONAL COMMENTS BY SPECIFIC ELECTRIFIED VEHICLE MODEL:

There are no additional comments beyond what has already been provided.

Comments by ICCT

CHARGE QUESTION	COMMENTS
1. Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?	The proposed model looks comprehensive and of high fidelity enough to serve its purpose of quantifying the fuel economy, energy efficiency, and CO2 emissions of different powertrain typologies under a variety of operating conditions for several technology choices. The main issue that needs clarification at this stage is the powertrain components' sizing and scaling approach. The process seems to be technology agnostic. For example, in the case of electric motor-generator scaling, the model appears to rely on one electric motor data-driven model reflecting a specific motor technology. We are not sure if this is only the case for the shared demo version of the tool and if the complete ALPHA model already includes several components' technologies. If that is the case, please disregard this comment. While the model is clear regarding technology choices focusing on hybrid-electric and pure- electric powertrains, it remains unclear why fuel-cell powertrains are excluded from the model.
2. What is the appropriateness and completeness of the overall model structure and its components, such as: o The breadth of component models/technologies compared to the current/future light-duty fleet o The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component. o The input and output structures and how they interface with the model to	**<u>The breadth of component models/technologies compared to the current/future light-duty fleet.</u>** The different technology and modeling choices are all reasonable. Special attention has been given to the hybrid powertrain controllers, one of the main fuel economy drivers. The P2-PHEV controller, as an example, seems to utilize a charge-depleting charge-sustaining strategy depending on the battery state-of-charge (SoC) and the physical constraints of the different energy conversion devices. During the charge-sustaining mode, the algorithm seems to try to operate the engine at its minimum BSFC line as much as possible. Assuming that this is the only modeled

CHARGE QUESTION	COMMENTS
obtain the expected result, i.e., fuel/energy consumption and CO_2 over the given driving cycles. o The use of default or dynamically generated values to create reasonable models from limited data sets.	control strategy, the question here is about the representativeness of this control strategy. Other more complex and efficient controllers, such as the ECMS (equivalent consumption minimizing strategy) based on Pontryagin's Maximum Principal optimization techniques, can reduce total fuel and energy consumption, and several vehicle manufacturers have considered it. While on the other hand, other simpler heuristics rule-based controllers can also be implemented. In addition, the domain of hybrid vehicle controllers has been going beyond the traditional optimization-based or rule-based methods as more advanced neural network- and machine learning-based control strategies are under continuous development. So, the question here is mainly about the representativeness of the adopted control strategy. In the generated results file in MATLAB workspace, there is a mention of a "s_factor," which seems drive cycle dependent. It is unclear why this factor is defined and how it is used in the model. This question is raised here as the "s_factor" is a common notion in the academic literature regarding hybrid vehicles' control strategies which is defined as a conversion factor between fuel energy and battery energy. **The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.** The battery model is a resistance-capacitance (RC) equivalent circuit model that captures the dynamic battery voltage drop as a function of the battery's main state variables, such as SoC and temperature. RC equivalent circuit models are proven to be robust models and widely used in battery modeling for vehicle energy assessment. The battery model also includes a thermal sub-model where

CHARGE QUESTION	COMMENTS
	the battery temperature and different heat transfer phenomena are estimated. The battery's internal heat generation due to the exothermic chemical reactions is well presented. The battery heat exchange with its surroundings, either with the ambient or the cooling system, seemed to be simplified in a single parameter: the battery pack's total conductance. It is unclear to us what battery cooling technologies are considered and to what extent this approach can consider different cooling techniques, such as active/passive air or liquid cooling. While this issue might not be a game changer in hybrid powertrains, the battery temperature is more critical on pure electric powertrains, given the size of the battery, which would affect the battery performance and total energy consumption. In addition, the battery efficiency seems to be quite high (96.9% on UDDS_1, 97.7% on UDDS_2, 98.7% on highway cycle, 91.8% on US06_1, 97.3% on US06_2). The electric machine model is mainly data-driven, summarized in dynamic look-up tables focusing on the maximum torque curves and energy conversion efficiency. It is unclear whether the model differentiates between continuous and peak torque. The electric machine losses seem to be quite high (23% on UDDS_1, 29% on UDDS_2, 15% on highway cycle, 26% on US06_1, 14% on US06_2). It is not clear if these are losses during both propulsion and regenerative braking modes. The different transmission systems and the engine are developed with high fidelity. The gear- shifting strategy behaved as expected for some sample runs. The transmission system model is highly complex, which raises the concern of data availability for model calibration for different vehicles. The powertrain auxiliaries, such as the air conditioning (AC) unit, fan, pump, and other electric auxiliaries, seemed to be modeled simply as constant power demand from the battery or torque demand from the engine. While this

CHARGE QUESTION	COMMENTS
	simplification is acceptable for most auxiliaries, such an approach can misestimate the AC/heating unit energy consumption, which is highly sensitive to dynamic operating conditions such as external temperature and trip duration. Detailed vehicle cabin thermal and AC/heating models would enhance the model capabilities to model the AC energy consumption providing a more accurate estimation of the vehicle's fuel economy/energy efficiency. Although the user can still input different auxiliary consumption in kW to mimic additional heating and cooling needs, quantifying such metric is a complex process that may incur inaccuracies. Thus, modeling such behavior is quite essential. The academic literature has grown rich recently with modeling techniques to integrate vehicle powertrain and vehicle cabin thermal modeling into a single platform. Some examples of such literature are: - Marcosa, D., Pinob, F.J, Bordonsa, C., Guerrab, J.J., "The development and validation of a thermal model for the cabin of a vehicle" Applied Thermal Engineering, https://doi.org/10.1016/j.applthermaleng.2014.02.054. - Doyle, A., Muneer, T., "Energy consumption and modeling of the climate control system in the electric vehicle". Energy Exploration & Exploitation, https://doi.org/10.1177/01445987188064. Regarding the drive cycles, it appears that the US06 drive cycle is split into two phases, with the first phase incorporating the hard accelerations and the second phase incorporating the high speeds. We recommend adding a combined US06 audit. **The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel/energy consumption and CO2 over the given driving cycles.**

CHARGE QUESTION	COMMENTS
	The output file structure looks appropriate and complete. The model, however, lacks a master input file where the user can easily visualize all inputs. While this is understandable for a non-commercial model, a master input file would ease model validation and allow the user to conduct parametric studies more easily, which would help provide a more solid idea of the entire model's robustness. **<u>The use of default or dynamically generated values to create reasonable models from limited data sets.</u>** While a data-driven modeling approach is reasonable for vehicle fuel economy estimation, a significant amount of data must be collected or provided to parametrize the model correctly. Engine test benches and vehicle chassis dynamometers are well-developed standard practices for data collection for conventional powertrain technologies. However, it is unclear how data for batteries and electric machines were developed and the extent to which such data collection methods are well developed. While this review covers the modeling approach in general, clarifying the electric components' data collection approaches via proper documentation is essential for the user to understand the potential limitations of the model.
3. Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?	It is not possible to provide a solid opinion about engineering judgment and model robustness without a thorough comparison between simulation results and real-world testing data at the component level and vehicle level. The peer reviewers asked EPA if ALPHA has been validated against real-world results. EPA answered that each sub-model had been thoroughly validated against data collected from vehicle dynamometer testing internally and externally, where the tested vehicle behavior was reproduced with the model. The general approach of the model validation process, as shared by EPA, sounds reasonable and comprehensive. The modeling run demos provided by EPA demonstrate good agreement between

CHARGE QUESTION	COMMENTS
	simulation results and real-world data, but a more robust assessment is beyond the scope of our review. One important point to mention is the impact of the simulation step size on the simulation error. While it is understood that a smaller step size would yield a lower error at the expense of higher computation resources, it is unclear how the simulation step size is set and what simulation error is considered acceptable.
4. Does the ALPHA model generate clear, complete, and accurate output/results (CO_2 emissions or fuel efficiency output file)?	The ALPHA model generates automatic plots describing the physical behavior of the main powertrain components, in addition to a console text file summarizing the energy consumption, fuel economy, and CO2 emissions. We recommend the following to make the results file more readable: - The accessory's energy consumption doesn't show the share of each component (fan, AC, pump, etc.). These are aggregated under one value. Although the generated results files contain placeholders for these accessories, they show a value of zero. - There is no mention of the battery's thermal needs as an accessory consumption. Is battery cooling/heating consumption considered part of the battery losses? It is worth documenting how the model handles battery thermal needs. - The results file mentions "kinetic energy" as a potential energy source in addition to fuel and stored energy. It is unclear whether this refers to brake energy recovery or another indicator. - The fuel energy could be further detailed into direct flow to the driveline or energy flow from the engine to the battery, depending on the powertrain architecture. This can provide a clearer idea of the control strategy under different drive cycles, operating conditions, and system boundary conditions.

CHARGE QUESTION	COMMENTS
	- In the model, it is mentioned that the final drive efficiency is already included in the electric drive unit. This is probably why the final drive losses are always set to zero in the results report. However, the final drive is separate from the electric motor, and combining their efficiencies limits the model's flexibility. We recommend fixing this issue.
5. Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?	- **Hybrid and plug-in hybrid vehicles' controllers** (energy management strategy) are rigid and developed based on specific strategies and algorithms. Providing the option to simulate several hybrid control strategies as part of the batch simulation runs would be more comprehensive and may cover a broader range of vehicles. - A **bottom-up approach** is recommended to estimate the vehicle weight. Estimating the components' weights and aggregating these weights to calculate the total vehicle weight can provide a more accurate estimation of the impact of different technology choices, especially different battery, and electric motor sizes. - **A master input file** can ease the execution of parametric studies and help validate the model's behavior and the component and system levels. - Improve the model **documentation** with explicit modeling assumptions, especially regarding hybrid controllers. - It is essential to provide insights into the representativeness of the **core data** used to develop these models. It is not entirely clear when these data were collected, how relevant they are today, and how relevant they will be in the long term.

ADDITIONAL OVERALL COMMENTS PROVIDED (NOT CHARGE QUESTION-SPECIFIC):
The review process of the ALPHA model considered both the provided MATLAB/Simulink scripts and models and the accompanying documentation. Generally, the different battery-electric and hybrid powertrain models are developed based on solid methodologies that capture state-of- the-art technologies with proper modeling techniques. The modeling approach is thorough and presents a comprehensive energy analysis of the different powertrain physical domains, where the sub-systems' interactions are clearly defined and well established. The core of the models mainly relies on a data-driven approach, where the physical behavior of the main powertrain components, such as the battery, electric machine, engines, etc., is captured using multidimensional data sets. This simplification is understandable at the powertrain system level, as simulating the dynamic physical behavior of every component would be beyond the scope of this model. The structure of the model is modular, allowing a standardized modeling and simulation environment for all powertrain technologies based on a common model core, as presented in the different libraries. The model includes a detailed set of controllers that dictate the behavior of the powertrain and permit communication among its components. The model architecture is well-organized and self-descriptive, helping the user navigate easily and making it less prone to logical and syntax errors. Finally, the model results are communicated through an output file summarizing the main key performance indicators at the system level, in addition to detailed output files describing the different components' behavior. Nonetheless, some assumptions at the component model and control levels are not clearly presented and require more clarification. These are discussed in more detail in question 2 in the responses to the charge questions. Finally, the provided documentation falls short of what would have been needed to develop a high-level understanding of the model structure and its input-output framework. The lack of proper documentation forces the user to dig deep into the code and structure of the models to understand the model's inner workings. While it is understood that such documentation is not meant for commercial use, a more organized summary of some critical assumptions would have been appreciated. This also renders more transparency to the overall data-driven modeling approach.
ADDITIONAL COMMENTS BY SPECIFIC ELECTRIFIED VEHICLE MODEL:
N/A

Appendix B: Peer Reviews Curriculum Vitae (CV)

VITA

SUJIT DAS

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OBJECTIVE

A professionally challenging R&D leadership position utilizing long years of experience in research, analysis, and knowledge dissemination on energy, water, and material efficiency in the manufacturing sector by developing and deployment, and promoting impactful practices, tools, and technologies

EDUCATION

MBA Management Science and Computer Science, University of Tennessee 1984

MS Metallurgical Engineering, University of Tennessee, 1982

B. Tech Metallurgical Engineering, Indian Institute of Technology, Kharagpur, India, 1979. Ranked 2nd in class with Honors.

PROFESSIONAL EXPERIENCE

2022 – Present Principal Engineer, Strategic Analysis, Inc. Arlington, VA

Manufacturing cost analysis of solid oxide electrolyser cell and fuel cell storage materials.

1984 - 1992 Research Associate, Energy Division, Oak Ridge National Lab, Oak Ridge, TN

1992 – 2005 R&D Staff Member, Energy Division, Oak Ridge National Lab, Oak Ridge, TN

2005 – 2022 Sr. Research Staff Member, Energy and Transportation Science Division, Oak Ridge National Laboratory, December 1984-present

A demonstrated long-term R&D team leader in the manufacturing energy efficiency research & analysis supported by a wide range of U.S. federal agencies (notably by various DOE/EERE offices and Fossil Energy), and industries. Technoeconomic, and life cycle energy and environmental, and manufacturing supply chain analyses have been the foundation R&D analysis supported the technology field-validation, verification, implementation of various early-stage various EERE office supported technologies to drive American competitiveness and innovation in energy, water, and material efficiency in the manufacturing sector. The analysis supported various ORNL program manager R&D activities across many divisions in various directorates in a wide range of technology areas, e.g., lightweight materials including advanced fibers and composites manufacturing, advanced clean energy manufacturing, vehicle manufacturing, water supply and demand, digital manufacturing, and electrification and energy infrastructures.

The Strategic Analysis of Advanced Manufacturing project supported by the DOE Advanced Manufacturing Office being led currently grew more than twice to a level of ~$900K in FY20 resulting in several new staff hire. Other new initiatives have been the multi-year technoeconomic and life cycle analysis of coal-to-products by the DOE Fossil Energy office. Several technoeconomic and life cycle energy models of advanced materials (e.g., carbon fiber and its composites are the only models used widely by various DOE/EERE offices, coal-to-products for the DOE Fossil Energy office), and clean energy manufacturing technologies (e.g., Additive manufacturing and Roll-to-Roll manufacturing) were developed. Decision-making tools for several resource markets such as petroleum and nuclear materials were developed in the past including the recent supply chain competitiveness analysis of clean energy manufacturing technologies (e.g., wide bandgap materials and semiconductor manufacturing), and integrated energy and desalination system design.

Collaborated with several industry partners in the techno-economic analysis of materials technologies for identifying commercialization opportunities in worldwide markets. Published research in referred journals and presented in international conferences. Several energy projects in developing countries such as Bangladesh and India were led in the past and recent invited talks on the life cycle analysis of lightweight materials were in Canada, China, and Europe. The following list provides highlights of multi-disciplinary and a wide range of manufacturing energy efficiency research and analysis projects in the areas of energy, water, and material efficiency led:

- Strategic analysis of semiconductor, smart, carbon fiber composites and water use in the advanced manufacturing for the EERE AMO Office
- Techno-economic and life cycle energy analysis of coal-to-products, e.g., carbon fiber composites and building insulation materials for the DOE Fossil Energy Office
- Integrated energy and desalination system design and industrial water use for the DOE
- Lead author of Technology Assessment of Thermoelectric and Wide Band Gap materials for the ongoing U.S. Dept. of Energy Quadrennial Technology Review
- Techno-economic and life cycle analysis of carbon fiber composites for the Wind Energy Technologies office
- Life Cycle Energy and Environmental Assessment of Aluminum-Intensive Vehicle Design
- Life Cycle Energy and Environmental Assessment of Multi-Material Lightweight Vehicles
- Supply Chain Manufacturing Competitiveness Analysis of Additive Manufacturing, Carbon Fiber, and Wide Band Gap Materials for U.S. Dept. of Energy
- Next generation materials with energy/emissions reduction potential in the U.S. industry for DOE Advanced Manufacturing Office
- Systems Analysis for the U.S. Dept. of Energy Fuel Cell Technologies Office

- Manufacturing process modeling of high temperature stationary fuel cell systems in the 350-400 kW power range for DOE Fuel Cell Technologies Program
- Life cycle modeling of alternative lightweight engine design options for the DOE Propulsion Materials Program
- Market potential and infrastructure assessment of ethanol and hydrogen as alternative transportation fuels
- Cost modeling and life cycle analysis of advanced vehicles and lightweight materials technologies for DOE Office of Vehicle Technologies
- Material technology assessments related to Partnership for A New Generation of Vehicles PNGV)/Freedom Cooperative Automotive Research (FreedomCAR)
- Potential of renewable energy technologies in rural Bangladesh
- Biomass refinery analysis
- Economic analysis of advanced power electronics, electric motors, and intelligent transportation systems
- Energy efficiency of distribution transformers
- Cost of alternative fuels
- Forecasting of petroleum and uranium supplies
- Estimation of flood-stage economic damages
- The economic viability of plastics and automobile recycling
- Environmental implications of privatization of the power sector in India
- Market assessments of energy efficient technologies such as home refrigerators in India
- Inspection and Maintenance of two-wheeler vehicles in India
- Assessment of uranium resources

Visiting Fellow, Tata Energy Research Institute (TERI), New Delhi, India, October 1992-June 1993.

Developed a comprehensive, computerized, and PC-based Energy-Economic-Environment database for TERI -- the first of its kind in India and provided technical support in their ongoing energy and economic modeling activities.

Research Assistant, Energy and Economic Analysis Section, Oak Ridge National Laboratory, September 1982-December 1984.

Documented and evaluated several EIA, DOE maintained computers models, i.e., Headwater Benefit Energy Gains Model and the Petroleum Allocation Model. Developed a computer software "BIOCUT" for Economic Evaluation Model for Wood Energy Plantations.

LIST OF PUBLICATIONS

BOOK/CHAPTERS PUBLISHED

"Recycling and life cycle issues for lightweight vehicles," A Book Chapter in Materials, Design and Manufacturing for Lightweight Vehicles 2e by Elsevier Inc. (Forthcoming 2020)

Two book chapters published in "Advanced Composite Materials for Automotive Applications: Structural Integrity and Crashworthiness," Edited by Ahmed Elmarakbi, Univ. of Sunderland, UK and published by Wiley & Sons (Aug.'13)

Chapter 3: Low Cost Carbon Fibre for Automotive Applications (Part 1: Low Cost Carbon Fibre Development); Chapter 17: Low Cost Carbon Fibre for Automotive Applications (Part 2: Applications, Performance and Cost Reduction Models)

"Recycling and Life Cycle Issues for Lightweight Vehicles," A Book Chapter in Materials, Design and Manufacturing for Lightweight Vehicles, edited by P.K. Mallick, Woodhead Publishing Limited, pp. 309-330, 2010

"Material Use in Automobiles." A Book Chapter in Encyclopedia of Energy, published by Elsevier Inc., Vol. 3, pp. 859-869, 2004.

"Plastic Wastes: Management, Control, Recycling, and Disposal." Noyes Data Corporation, NJ (Co-Authored with U.S. Environmental Protection Agency and T. R. Curlee), 1991.

SELECTED REFERRED ARTICLES/PRESENTATIONS (Out of 100+ articles and presentations)

"The Global Energy Footprint of Information And Communication Technology Electronics In Connected Internet-Of-Things Devices," Journal of Sustainable Energy, Grids and Networks, Nov. 2020 https://doi.org/10.1016/j.segan.2020.100408 (Das et al.)

"Leveraging Flexible Smart Manufacturing to Accelerate Industrial Supply Chain Recovery" Journal of Smart and Sustainable Manufacturing Systems Nov. 2020 DOI: 10.1520/SSMS20200056 (Terry et al.)

"The Energy Footprint of Automotive Electronic Sensors," *Sustainable Materials and Technologies,* Volume 25, September 2020, e00195, https://doi.org/10.1016/j.susmat.2020.e00195 (Armstrong et al.)

"Optimized Carbon Fiber Composites in Wind Turbine Blade Design," SAND2019-14173, Sandia National Laboratories, Albuquerque, NM Oct. (with Ennis et al.)

"Technoeconomic Analysis of Coal Pitch Carbon Fiber Manufacturing," presentation at the Carbon 2019 conference, held in Lexington, KY on July 14-19, 2019 (Das, S.)

"Global Carbon Fiber Composites Supply Chain Competitiveness Analysis," Technical Report, Oak Ridge National Laboratory, Oak Ridge, TN. (Das, S. et al.)

"Life Cycle Energy Impacts of Automotive Electronics," *Smart and Sustainable Manufacturing Systems* 1, no. 1 (2017): 262-288; *https://doi.org/10.1016/j.susmat.2020.e00195* (Cassorla et al.)

"Vehicle Lightweighting Energy Use Impacts in US Light-Duty Vehicle Fleet,"Sustainable Materials and

Technologies, Vol. 8, July, p. 5-13 (2016).

"Innovation in Engineering Plastics, Carbon Fiber & Composites," invited presentation at the Advanced Design & Manufacturing conference, held in Cleveland, OH on Mar. 29-30,'17.

"OEM Strategies on LightWeight Metals" invited presentation at the Advanced Lightweight Vehicles and Materials 2016 Forum, held on 13-14 Oct.'16, Berlin, Germany.

"Life Cycle Analysis of Automotive Electronics," paper presented at the ACLCA XIV conference, held on Sept. 27-29,'16 in Charleston, SC.

"Carbon Fiber Composites in High Volume Ground Transportation: Competition Between Alternatives," paper prepared for presentation and publication at *CAMX to be held on Oct. 13-16,'14 in Orlando, Fl.*

"Life Cycle Energy and Environmental Assessment of Aluminum-Intensive Vehicle Design," SAE Paper No. 14M-0325, Warrendale, PA (Apr. 14). Also published in the *SAE International Journal of Materials and Manufacturing*, June 2014.

"Aluminum's Environmental Superiority in Automotive Reaffirmed by Oak Ridge National Laboratory -- Aluminum Offers Smallest Total Carbon Footprint Among Competing Materials" – DRIVE ALUMINUM press release on Apr. 9 *(News Article published on April 10, 2014: http://www.greencarreports.com/news/1091379_aluminum-vehicles-save-more-energy-than-it-takes-to-build-them)*

"Global Carbon Fiber Composites Supply Chain Competitiveness Analysis," draft report for the DOE Strategic Planning Assessment Office, May 2014.

"Metal Flow, Recycling, Energy and Environment: Al, Cu, Mg and Ti", Paper presented at the TMS Annual Meeting on Feb. 18, '14

"Cost of Ownership and Well-to-Wheels Carbon Emissions/Oil Use of Alternative Fuels And Advanced Light-Duty Vehicle Technologies, " *Energy for Sustainable Development* Vol. 17 (6), pp. 626–641, December 2013

"Vehicle Lightweighting – A Sustainable Pathway in the Transport Sector?" Invited paper presentation at IUMRS-ICAM2013 Intl. Conference on Advanced Materials, Qingdao, China, Sept. 22-28, 2013.

"Platinum Group Metals (PGM) for Light-Duty Vehicles", Fuel Cell Technologies Program Record, U.S. Dept. of Energy, Sept. 2013.

"Manufacturing Process Modeling of 100-400 kWe Combined Heat and Power for Stationary Fuel Cell Systems," Paper no. ESFuelCell2012-91183, *Proceedings of the ASME 2012 6th International Conference on Energy Sustainability & 10th Fuel Cell Science, Engineering and Technology Conference*, held on July 23-26, 2012, San Diego, CA.

Served as one of the expert reviewers for the following four recent U.S. DOT/U.S. EPA reports

"NHTSA fuel economy rule making draft report "Mass Reduction for Light-Duty Vehicles for Model Years 2017-25" (2016)

"EPA Advanced Light-Duty Powertrain Hybrid Analysis (ALPHA) Model"(2016)

"Vehicle Mass Reduction and Cost Analysis – Heavy Duty Pickup Truck and Light Commercial Vans" report for EPA (2016)

"Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies," Tetra Tech, Inc./NHTSA, Feb. '15.

"Mass Reduction and Cost Analysis – Light-Duty Pickup Trucks Model Years 2020-2025," FEV, Inc./EPA, July,'14.

"Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025," EDAG/The George Washington University Report, Apr. 2012

"Light-Duty Technology Cost Analysis Pilot Study, FEV Draft Report, "Sept. 3, 2009
"An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program," Lotus Engineering Inc., Mar. 2010

"Lightweighting Opportunities in the Global Automotive Industry," invited presentation at the 2011 International Automotive Lightweight Materials Development Forum, held in Chongqing, China, on Mar. 24-25,'11. (Also at the 12th IUMRS International Conference on Advanced Materials, held in Qingdao, China on Sept. 22-28, 2013)

"Importance of Economic Viability Assessment of Automotive Lightweight Materials" invited presentation at the 3rd Annual Advanced Lightweight Materials for Vehicles conference held on Aug. 11-12, '10, Detroit, MI.

"Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints," Transportation Research Record: Journal of the Transportation Research Board, No. 2168, Transportation Research Board of the National Academies, Washington, DC, 2010, pp. 136-145.

"Reducing GHG Emissions in the United States' Transportation Sector" Energy for Sustainable Development, 15 (2011) 117–136, May 11.

"Life Cycle Assessment of Carbon Fiber-Reinforced Polymer Composites," Intl. Journal of Life Cycle Assessment, Volume 16, Issue 3, pp. 268-282, 2011

"Battle Green," an interview article published in American Metal Market, Oct. 2010, pp. 36-40.

"Shedding Pounds On a Magnesium Diet," Automotive Engg. International, Apr. 6, 2010, pp. 34-36, interview article by Steven Ashley.

"Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints," Transportation Research Record: Journal of the Transportation Research Board, No. 2168, Transportation Research Board of the National Academies, Washington, DC, 2010, pp. 136-145.

"Low-Carbon Fuel Standard – Status and analytic issues," Energy Policy, vol. 38, No.1, Jan. 2010, pp. 580-591.

"Importance of Economic Viability Assessment of Automotive Lightweight Materials," invited presentation at the 3rd Annual Advanced Lightweight Materials for Vehicles," held in Detroit, MI on Aug. 11-12, 2010.

"A Comparative Life Cycle Assessment of Magnesium Front End Parts," SAE Paper No. 2010-01-0275, Society of Automotive Engineers, Warrendale, PA.

"Primary Magnesium Production Costs for Automotive Applications," Journal of Metals, Vol. 60, No. 11, 2008, pp. 51-58.

"A Systems Approach to Life Cycle Truck Cost Estimation," SAE Paper No. 2006-01-3562, Society of Automotive Engineers, Warrendale, PA.

"Automotive Lightweighting Materials Benefit Evaluation," ORNL/TM-2006/545, Oak Ridge National Laboratory, Oak Ridge, TN, Nov. 2006

"Lightweight Opportunities for Fuel Cell Vehicles," SAE Paper No. 2005-01-0007, Society of Automotive Engineers, Warrendale, PA.

"A Comparative Assessment of Alternative Powertrains and Body-in-White Materials for Advanced Technology Vehicles," SAE Paper No. 2004-01-0573, Society of Automotive Engineers, Warrendale, PA.

"Back To Basics? The Viability of Recycling Plastics by Tertiary Approaches," Working Paper #5, Program on Solid Waste Policy, School of Forestry and Environmental Studies, Yale University, New Haven, CT, September 1996.

"Determination Analysis of Energy Conservation Standards for Distribution Transformers. ORNL-6847, Oak Ridge National Laboratory, Oak Ridge, TN, July 1996.

AWARDS & PROFESSIONAL ACTIVITIES

Ranked within the top 2% of world scientists in the Energy research discipline for 2019 Citation Impact

One of the instructors on the Lightweight Innovations for Tomorrow (LIFT) Advanced Materials for Case Western Reserve University Siegel Continuing Professional Studies (CWRU) program -- 2018

Recipient of the 2017 U.S.-Israel Integrated Energy and Desalination System Design Challenge Winner of the U.S. Department of Energy Policy and Systems Analysis Office

Recipient of the Society of Automotive Engineers 2015 Forest R. McFarland Award

Three-year (2016-2019) term as a Member-At-Large of SAE Engineering Meetings Board

American Center for Life Cycle Assessment Policy Committee member (2018-Present

Awarded 2004 Journal of Metals Best Paper by the Mineral, Metals, and Materials Society (TMS)

Chair of Society of Automotive Engineering (SAE) Sustainable Program Development Committee (Jan. 2013- Dec. 2014)

Member of Transportation Research Board (TRB) Committees (2008- 2016)
Transportation Economics
Alternative Transportation Fuels and Technologies

Invited Speaker on the Life Cycle Assessment of Materials by Beijing University of Technology, China

Conference Session Organizers for SAE and TRB

Research proposal review committee member of National Sciences and Engineering Council of Canada

External Peer Reviewer of EPA's draft report on vehicle mass reduction and cost analysis of light-duty car and pickup truck, and medium- and heavy-duty vehicles

Peer Reviewer for National Sciences and Engineering Council of Canada

Peer Reviewer for Several Energy and Environmental Related Journals

CURRICULUM VITAE
SHAWN W. MIDLAM-MOHLER

Current Appointments:

Professor of Practice – Primary Appointment Ohio State University Department of Mechanical and Aerospace Engineering, Columbus, OH	8/2019 to present
Director Ohio State University Simulation Innovation and Modeling Center, Columbus, OH	7/2017 to present
Fellow Ohio State University Center for Automotive Research, Columbus, OH	8/2012 to present

Education:

Ph.D.	Mechanical Engineering		6/2005
	The Ohio State University	Columbus, OH	
	Dissertation Title: "Modeling, Control, and Diagnosis of a Diesel Lean NO_x Trap Catalyst"		
M.S.	Mechanical Engineering		3/2001
	The Ohio State University	Columbus, OH	
	Thesis Title: "A Novel Fuel-Operated Heater for Automotive Thermal Management"		
B.S.	Mechanical Engineering	*Summa cum Laude, 4.0 GPA*	6/1999
	Wright State University	Dayton, OH	

Academic Experience:

Associate Professor of Practice Ohio State University Department of Mechanical and Aerospace Engineering, Columbus, OH	9/2015 - 8/2019
Associate Director Ohio State University Simulation Innovation and Modeling Center, Columbus, OH	1/2014 - 6/2017
Assistant Professor of Practice Ohio State University Department of Mechanical and Aerospace Engineering, Columbus, OH	8/2012 - 8/2015
Research Scientist Ohio State University Center for Automotive Research, Columbus, OH	10/2008 - 7/2012
Senior Research Associate Ohio State University Center for Automotive Research, Columbus, OH	11/2005 - 9/2008
Research Associate II Ohio State University Center for Automotive Research, Columbus, OH	2/2004 - 10/2005

Professional Licenses:

Professional Engineer State of Ohio	License 75703 Inactive

Project Management Professional Project Management Institute	License 1622962 Inactive

Awards:

National Science Foundation Outstanding Faculty Advisor Award 5/2018
- Presented to the EcoCAR faculty advisor who best promotes the goals, objectives, and activities related to the EcoCAR student design competition

Honda-OSU Partnership Award 5/2016
- Presented to an individual who has made significant contributions towards promoting and strengthening the Honda-OSU Partnership

Outstanding Faculty Advisor - Ohio State University College of Engineering 2/2015
- Presented to most impactful faculty advisor of student engineering teams in the College

Applied Automotive Engineering Fellow - Department of Energy 6/2015
- Presented to acknowledge significant contributions to applied automotive engineering research and education

Outstanding Technology Team – TechColumbus 2/2012
- Presented to a team of OSU-CAR faculty and research staff because of their extensive partnerships driving technology forward in Ohio

National Science Foundation Outstanding Incoming Faculty Advisor Award 7/2011
- Presented to the junior EcoCAR faculty advisor who best promotes the goals, objectives, and activities related to the EcoCAR student design competition

TEACHING AND MENTORING

Doctoral Student Advised:

1. 2015 – 2019 Vivek Bithar. The Ohio State University. Robust MPC-Based Motion Planning and Control of Autonomous Ground Vehicles. 2019.
2. 2014 – 2020 Greg Jankord. The Ohio State University. Control of Criteria Emissions and Energy Management in Hybrid Electric Vehicles with Consideration of Three-Way Catalyst Dynamics. 2020.
3. 2017 – 2020 Phillip Aquino. The Ohio State University.
4. 2014 - 2021 David Hillstrom. The Ohio State University.
5. 2016 – 2021 Wilson Perez. The Ohio State University.
6. 2015 – Present Aditya Karamanchi. The Ohio State University.
7. 2021 – Present Eric Belknap. The Ohio State University
8. 2021 – Present Mayur Patil. The Ohio State University

Doctoral Students Mentored & Funded[1]

1. 2010-2012 Qiuming Gong. The Ohio State University.
2. 2009-2011 Jason Meyer. The Ohio State University.
3. 2007-2010 Kenny Follen. The Ohio State University.

[1] Prior to becoming a Professor of Practice, Dr. Midlam-Mohler was not permitted co-advisor status of PhD students

Masters Student (Advisor / Lead Co-Advisor)

1. M. Fang, Analysis of Variability and Injection Optimization of a Compression Ignition Engine, 2009.
2. R. S. Maringanti, Inverse-Distsance Interpolation Based Setpoint Generation Methods for Closed-Loop Combstion Control of a CIDI Engine, 2009.
3. C. M. Hoops, Uncertainty Analysis for Control Inputs of Diesel Engines, 2010.
4. R. B. Cooley, Engine Selection, Modeling, and Control Development for an Extended Range Electric Vehicle, 2010.
5. B. Bezaire, Modeling and Control of an Electrically-Heated Catalyst, 2011.
6. R. V. Everett, An Improved Model-Based Methodology for Calibration of an Alternative Fueled Engine, 2011.
7. J. M. Davis, Diesel Engine Experimental Design and Advanced Analysis Techniques, 2011.
8. Gupta, Characterization of Engine and Transmission Lubricants for Electric, Hybrid, and Plug-in Hybrid Vehicles, 2012.
9. M. Garcia, Feed-Forward Air-Fuel Ratio Control during Transient Operation of an Alternative Fueled Engine, 2013.
10. N. Hyde, Development of a Traction Control System for a Parallel-Series PHEV, 2014.
11. S. Gurusubramanian, A comprehensive process for Automotive Model-Based Control, 2013.
12. T. Ma, Model-Based Control Design and Experimental Validation of an Automated Manual Transmission, 2013.
13. N. V. Baradwaj, Uncertainty Analysis of Resistive Soot Sensors for On-Board Diagnostics of Automotive Particulate Filters, 2013.
14. S. A. Ramirez, Supervisory Control Validation of a Fuel Cell Hybrid Bus Using Software-in-the-Loop and Hardware-in-the-Loop Techniques, 2013.
15. M. J. Organiscak, Model Based Suspension Calibration for Hybrid Vehicle Ride and Handling Recovery, 2014.
16. D. R. Hillstrom, Light Duty Natural Gas Engine Characterization, 2014.
17. T. Mukherjee, One Dimensional Air System Modeling of Advanced Technology Compressed Natural Gas Engines, 2014.
18. S. Shivaprasad, Model Based Investigation of Lean Gasoline PM and NOx Control, 2014.
19. E. M. Gallo, Development of Series Mode Control of a Parallel-Series Plug-In Hybrid Electric Vehicle, 2014.
20. W. Spiegel, A Soft ECU Approach to Develop a Powertrain Control Strategy, 2015.
21. B. Hegde, Look-Ahead Energy Management Strategies for Hybrid Vehicles., 2018.
22. J. Ward, Modeling and Simulating a Performance Hybrid Electric Vehicle, 2015.
23. S. Yacinthe, System Safety Development of a Performance PHEV Through a Model-Based Systems Engineering Approach, 2016.
24. Khanna, Full-Vehicle Model Development of a Hybrid Electric Vehicle And Development of a Controls Testing Framework, 2016.
25. L. A. Cardinale, Automating the Subjective Analysis of Knock during Hot Engine Starts, 2016.
26. J. Mack, Calibration of Automotive Aftertreatment Models through Co-Simulation with MATLAB Optimization Routines, 2016.
27. M. J. Yatsko, Development of a Hybrid Vehicle Control System, 2016.
28. C. Huester, Design and Validation of an Active Stereo Vision System for the OSU EcoCAR 3, 2017.
29. Modak, Modeling and Control of an Automated Manual Transmission for EcoCAR 3 Vehicle, 2017.
30. D. S. Kibalama, Design and Implementation of a Belted Alternator Starter System for the OSU EcoCAR 3 Vehicle, 2017.
31. B. Bishop, Model-Based Suspension Optimization of the Ohio State EcoCAR 3 Vehicle, 2018.
32. S. J. Trask, Systems and Safety Engineering in Hybrid-Electric and Semi-Autonomous Vehicles, 2019.
33. M. A. Mandokhot, Development of Predictive Gasoline Direct Fuel Injector Model for Improved In-cylinder Combustion Characterization, 2018.
34. E. G. Clepper, Agile Project Management/Systems Engineering of an AV Interior Prototype, 2018.
35. A. Thomas, Modeling and Performance Analysis of a 10-Speed Automatic Transmission for X-in-the-Loop Simulation, 2018.
36. J. Hurd, Design of Reconfigurable Interior for Autonomous Vehicle Prototype, 2018.
37. K. B. Kavathia, Uncertainty Analysis of an Engine Test Cell, 2018.

38. S. K. Sahu, Model-Supported Heat- Flux Sensor Development, 2018.
39. U. R. Gambhira, Powertrain Optimization of an Autonomous Electric Vehicle, 2018.
40. E. Stoddart, Computer Vision Techniques for Automotive Perception Systems, 2019.
41. 2018 – 2020 P. Dalke. The Ohio State University.
42. 2018 – 2020 M. Patil. The Ohio State University.
43. 2018 – 2020 K. Kuwabara. The Ohio State University.
44. 2018 – 2020 L. Longmire. The Ohio State University.
45. 2018 – 2020 M. Satra. The Ohio State University.
46. 2019 – 2020 J. Karl-DeFrain. The Ohio State University.
47. 2019 – 2020 S. Goel. The Ohio State University.
48. 2019 – 2020 A. Narasimhan. The Ohio State University.
49. 2019 – 2020 K. Gena. The Ohio State University
50. 2019 – 2021 H. Rangarajan. The Ohio State University.
51. 2018 – 2021 Y. Jin. The Ohio State University.
52. 2019 – 2021 TJ Kirby. The Ohio State University.
53. 2020 – 2021 Vikhyat Kalra. The Ohio State University.
54. 2020 – 2021 Kanna Sundararaman Venkateshwara. The Ohio State University.
55. 2020 – 2021 Iric Bernal. The Ohio State University.
56. 2020 – present Mia Bridgman. The Ohio State University.
57. 2020 – present Vincente Capito-Ruiz
58. 2020 – present Gage Sovey. The Ohio State University.
59. 2020 – present Colin Knight. The Ohio State University.
60. 2021 – present Ron Smith. The Ohio State University.
61. 2021 – present Shaumya Jha. The Ohio State University.
62. 2022 – present Abhijeet Killol. The Ohio State University.
63. 2022 – present Kami Russell. The Ohio State University.
64. 2022 – present Karun Singh. The Ohio State University.

MS Students Mentored and Funded:[2]

1. Eric Snyder, 2005. The Ohio State University.
2. Adam Vosz, 2006. The Ohio State University.
3. Courtney Coburn, 2006. The Ohio State University.
4. Kenny Follen, 2007. The Ohio State University.
5. Josh Cowgill, 2007. The Ohio State University.

Visiting Scholars Supervised:

The following individuals conducted research at Ohio State for periods of 3 – 12 while completing MS/PhD programs at other institutions.

1. Simone Bernasconi, 2007, The Ohio State University.
2. Patrick Rebechi, 2008, The Ohio State University.
3. Andrea Pezzini, 2008, The Ohio State University.
4. Adalbert Wolany, 2009, The Ohio State University.
5. Bernhard Grimm, 2010, The Ohio State University.
6. Asier Martinez, 2011, The Ohio State University.
7. Dennis Kibilama, 2014, The Ohio State University.
8. Africa Junior, 2014, The Ohio State University.
9. Tom Kigezi, 2014, The Ohio State University.
10. Guido Guercioni, 2016, The Ohio State University.
11. Vincente Capito, 2019, The Ohio State University.

Undergraduate Research (Advisor/Supervisor)

[2] These students were mentored by Dr. Midlam-Mohler as a staff member prior to having advising status

1. 2006 – 2007 Rhisee Bhatt. The Ohio State University.
2. 2007 Joshua Supplee. The Ohio State University.
3. 2008 John Lutz. The Ohio State University.
4. 2008 Konrad Svzed. The Ohio State University.
5. 2008 – 2009 Chris Hoops. The Ohio State University.
6. 2008 – 2009 Al Godfrey. The Ohio State University.
7. 2009 Ross Want. The Ohio State University.
8. 2009 Sean Ewing. The Ohio State University.
9. 2009 David Griffin. The Ohio State University.
10. 2009 – 2010 Jennifer Loy. The Ohio State University.
11. 2009 – 2010 John Macauley. The Ohio State University.
12. 2009 – 2010 Alixandra Keil. The Ohio State University.
13. 2009 – 2010 Andrew Arnold. The Ohio State University.
14. 2009 – 2010 Ryan Everett. The Ohio State University.
15. 2009 – 2010 John Davis. The Ohio State University.
16. 2009 – 2010 Katherine Bovee. The Ohio State University.
17. 2010 – 2013 Sarah Jadwin. The Ohio State University.
18. 2010 – 2011 Abbey Underwood. The Ohio State University.
19. 2011 Jerrin Lutcsh. The Ohio State University.
20. 2012 – 2013 Tom Brown. The Ohio State University.
21. 2012 – 2013 Jason Ward. The Ohio State University.
22. 2012 – 2013 Tyler Joswick. The Ohio State University.
23. 2012 – 2013 Sarah Vasey. The Ohio State University.
24. 2012 – 2013 Andrew Speigel. The Ohio State University.
25. 2013 – 2014 Bryan Silverman. The Ohio State University.
26. 2013 – 2014 MJ Yatsko. The Ohio State University.
27. 2013 – 2014 Gaurav Krishnaraj. The Ohio State University.
28. 2012 – 2014 Arjun Khanna. The Ohio State University.
29. 2016 – 2017 Shuhan Yang. The Ohio State University.
30. 2017 – 2018 Briana Antorino. The Ohio State University.
31. 2018 – 2019 Jacqueline Karl-DeFrain. The Ohio State University.
32. 2018 – 2019 Alisson Mellor. The Ohio State University.
33. 2018 – 2019 Kristina Kuwabara. The Ohio State University.
34. 2018 – 2019 Phillip Dalke. The Ohio State University.
35. 2019 – 2020 Iric Bernal. The Ohio State University.
36. 2020 – 2020 Ron Smith. The Ohio State University.
37. 2021 – 2021 Kami Russell. The Ohio State University.
38. 2021 – 2022 James Enders. The Ohio State University

Research Staff Supervision:

Dr. Midlam-Mohler has supervised the following technical staff. Only their current/terminal position is listed.

1. 2014 - 2019 Punit Tulpule. Research Scientist. The Ohio State University.
2. 2015 – 2017 Ayyoub Rezaeian. Post-Doctoral Researcher. The Ohio State University.
3. 2015 – 2021 Emily Nutwell, Research Specialist. The Ohio State University.
4. 2015 – 2019 Sheng Dong, Research Scientist. The Ohio State University.
5. 2015 – 2019 Zhenyu Wang, Research Scientist. The Ohio State University.
6. 2015 – 2021 Raju Dantuluri. Senior Research Associate - Engineer. The Ohio State University.
7. 2017 – Present Satchit Ramnath, Research Associate 2 - Engineer. The Ohio State University.
8. 2017 – Present Peiyu Yang, Research Associate 2 - Engineer. The Ohio State University.
9. 2017 – 2019 Ali Nassiri, Research Scientist. The Ohio State University.
10. 2018 – 2020 Luke Fredette, Post-Doctoral Researcher. The Ohio State University.
11. 2019 – 2021 Rodrigo Auza Gutierrrez, Research Associate 2 – Engineer. The Ohio State University.

12. 2019 – 2020 Rasoul Esmaeilpour, Post-Doctoral Researcher. The Ohio State University.
13. 2021 – Present David Hillstrom, Research Specialist. The Ohio State University.
14. 2021 – Present Dennis Kibalama, Research Specialist. The Ohio State University.

Undergraduate and Graduate Courses:

Dr. Midlam-Mohler's teaching focuses on automotive technical electives and capstone senior design. His cumulative mean electronic student evaluation score for "Overall Rating" is 4.7 out of a 5 point scale.

Period Offered	Course Number and Title
Spring 2007	ME 730 Internal Combustion Engine Modeling
Winter 2009	ME 631 Automotive Powertrain Laboratory
Spring 2009	ME 730 Internal Combustion Engine Modeling
Winter 2010	ME 631 Automotive Powertrain Laboratory
Winter 2011	ENGR 659.01 Multidisciplinary Capstone 1
Winter 2011	ME 565.02 Mechanical Engineering Design 1
Winter 2011	ME 631 Automotive Powertrain Laboratory
Spring 2011	ENGR 659.02 Multidisciplinary Capstone 2
Spring 2011	ME 565.03 Mechanical Engineering Design 2
Winter 2012	ENGR 659.01 Multidisciplinary Capstone 1
Winter 2012	ME 565.02 Mechanical Engineering Design 1
Winter 2012	ME 631 Automotive Powertrain Laboratory
Spring 2012	ENGR 659.02 Multidisciplinary Capstone 2
Spring 2012	ME 565.03 Mechanical Engineering Design 2
Fall 2012	ME 4902.01 Mechanical Engineering Capstone 1
Spring 2013	ME 4902.02 Mechanical Engineering Capstone 2
Spring 2013	ME 5531 Automotive Powertrain Laboratory
Fall 2013	ME 4902.01 Mechanical Engineering Capstone 1
Fall 2013	ME 4194 Applied Project Management and System Engineering 1 (Pilot)
Spring 2014	ME 4902.02 Mechanical Engineering Capstone 2
Spring 2014	ME 5531 Automotive Powertrain Laboratory
Spring 2014	ME 4194 Applied Project Management and System Engineering 2 (Pilot)
Fall 2014	ME 4902.02 Engineering Capstone
Fall 2014	ME 5194 Applied Project Management and System Engineering 1
Spring 2015	ME 5531 Automotive Powertrain Laboratory
Spring 2015	ME 5194 Hardware-in-the-Loop for Control System Development (Pilot)
Spring 2015	ME 4902.02 Mechanical Engineering Capstone 2
Fall 2016	ME 5600 Applied Project Management and System Engineering
Fall 2016	ME 4902.02 Mechanical Engineering Capstone 1
Spring 2017	ME 4902.02 Mechanical Engineering Capstone 2
Fall 2017	ME 4902.02 Mechanical Engineering Capstone 1
Spring 2017	ME 5531 Automotive Powertrain Laboratory
Spring 2017	ME 4902.02 Mechanical Engineering Capstone 2
Autumn 2017	MECHENG 4902.01 ME Capstone Design II: Student Design Competitions
Spring 2018	MECHENG 5531 Automotive Powertrain Laboratory
Spring 2018	MECHENG 4902.02 ME Capstone Design III: Student Design Competitions
Spring 2018	ME 5531 Automotive Powertrain Laboratory
Autumn 2018	ME 4900 ME Capstone Design I
Autumn 2018	ME 4902.01 ME Capstone Design II: Student Design Competitions
Spring 2019	ME 4902.02 ME Capstone Design III: Student Design Competitions
Autumn 2019	ME 4900 ME Capstone Design I
Autumn 2019	ME 4902.01 ME Capstone Design II: Student Design Competitions
Spring 2020	MECHENG 4902.02 ME Capstone Design III: Student Design Competitions

Spring 2020	ME 5531 Automotive Powertrain Laboratory
Autumn 2020	ME 4900 ME Capstone Design I
Autumn 2020	ME 4902.01 ME Capstone Design II: Student Design Competitions
Spring 2021	MECHENG 4902.02 ME Capstone Design III: Student Design Competitions
Spring 2021	ME 5531 Automotive Powertrain Laboratory
Autumn 2021	ME 4900 ME Capstone Design I
Autumn 2021	ME 4902.01 ME Capstone Design II: Student Design Competitions

Curriculum Development – Internal:

ME 5531 Advanced Automotive Systems Analysis 2019
Ohio State University, Columbus, OH

- Redeveloped previous 5531 course to include autonomous vehicle sensing and electrified powertrains
- Reused < 50% of previous material
- Secured donations of equipment for the lab from Fiat Chrysler and Honda

ME 4900 ME Capstone Design I 2018
Ohio State University, Columbus, OH

- Developed a dedicated 4900 course for students engaged in the Student Design Competition Capstone
- Used < 5% of colleague's 4900 course material

ME 5600 Applied Project Management and System Engineering 2016
Ohio State University, Columbus, OH

- Developed new course based on MAE EAB feedback on value of course for our undergraduates
- Course immerses students in a system engineering and project management role-playing scenario

ME 5194 Hardware-in-the-Loop for Control System Development (Pilot) 2015
Ohio State University, Columbus, OH

- Developed new course on HIL to complement existing controls / system modeling courses
- Effort was funded via a competitive grant from The Mathworks

ME 565.02/.02 Mechanical Engineering Design 1 & 2 2011
Ohio State University, Columbus, OH

- Adapted existing MAE and ENGR to work with student design competition teams
- Developed sponsors to fund the activity fully and have never used department funds

ME 631 Internal Combustion Engine Modeling 2009
Ohio State University, Columbus, OH

- Redeveloped course with <25% reuse of previous lecture material and total redevelopment of assignments
- Developed content that walked students through building an entire engine model in stages, developed project that used industry-standard simulation package

ME 730 Internal Combustion Engine Modeling 2007
Ohio State University, Columbus, OH

- Redeveloped course with <10% reuse of previous material/labs
- Developed adaptable labs/content that utilized latest research engines/vehicles at CAR to provide industry-relevant experience for students

Curriculum Development – External:

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

Internal Combustion Engine Control 2015
Ohio State University, Columbus, OH
- Developed a 6 hour seminar from on IC engine control
- Supported by the Department of Energy

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

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

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

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

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

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

INTERNAL SERVICE

Simulation Innovation and Modeling Center, Director 2017 to present
Ohio State University, Columbus, OH
- Responsible for all Center leadership activities
- Supervise 3 business and 12 technical staff
- Grew center to $6.5M in research annual expenditures
- Supports research of more than 70 faculty, 30 graduate students, and 60 undergraduates

Simulation Innovation and Modeling Center, Associate Director 2014 to 2017
Ohio State University, Columbus, OH
- Responsible for day-to-day operation of the center
- Co-responsible for strategic leadership of the center

- Responsible for all hiring and staff performance
- Responsible for status reports to College and Honda

Business Staff Supervision:

1. 2015 – 2017 Alexis Duffy, Program Manager, The Ohio State University.
2. 2016 – Present Layla Mohamad-Ali, HR/Fiscal Generalist, The Ohio State University.
3. 2017 – Present Heather Sever, Associate Director, The Ohio State University.
4. 2017 – Present Amber Pasternak, Program Manager, The Ohio State University.
5. 2019 – Present Camille Weiker-Isaman, Program Assistant, The Ohio State University.

Internal Board/Committee Involvement:

Simulation Innovation and Modeling Center Steering Board 2014 to present
Ohio State University, Columbus, OH
- Work with other faculty to advance the mission of the SIMCenter

Center for Automotive Research Faculty Advisory Board 2014 to present
Ohio State University, Columbus, OH
- Work with other faculty to advance the mission of the Center for Automotive Research

MAE Graduate Admissions Committee 2012 to 2019
Ohio State University, Columbus, OH
- Reviews graduate student applications and recommends acceptance to the Department and consideration for Department and University fellowships

Student Organization Advising:

EcoCAR Mobility Challenge Hybrid / Autonomous Vehicle Team 8/2018 – present
Ohio State University, Columbus, OH
- Serve as lead co-adviser of a 40 member (~80% undergraduate) student design project team competing in U.S. Department of Energy sponsored vehicle competition
- The team won the competition in the first year along with multiple honors amongst the various award categories

EcoCAR 3 Hybrid Electric Vehicle Team 8/2014 – 5/2018
Ohio State University, Columbus, OH
- Serve as lead co-adviser of a 40 member (~80% undergraduate) student design project team competing in U.S. Department of Energy sponsored vehicle competition
- The team has won the competition in each of the four competition years along with multiple honors amongst the various award categories

EcoCAR 2 Hybrid Electric Vehicle Team 7/2011 – 6/2014
Ohio State University, Columbus, OH
- Served as lead co-adviser of a 40 member (~80% undergraduate) student design project team competing in U.S. Department of Energy sponsored vehicle competition
- The team finished 2nd place in the first year of competition, 3rd place in the second year, and 1st place the final year of the competition

EcoCAR Challenge Hybrid Electric Vehicle Team 6/2008 – 6/2011
Ohio State University, Columbus, OH
- Served as lead co-adviser of a 40 member (~80% undergraduate) student design project team competing in U.S. Department of Energy sponsored vehicle competition

- Team won 1st, 5th, and 2nd in the three years of competition and won numerous event awards

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

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

Diversity Activities

Dr. Midlam-Mohler EcoCAR team has won 10 awards for support of diversity in engineering. He has mentored three SROP students (URMs) and funded two of them as graduate students as they conducted their graduate studies at OSU.

EXTERNAL SERVICE

Service to Government Agencies:

EPA Vehicle System Model Reviewer 2016
Peer Reviewer

- Conducted a ~30 hour peer review of a system model for future vehicle technology used in making policy decisions for future fuel-economy regulations

NHTSA Automotive Technology/Policy Report Reviewer 2015
Peer Reviewer

- Conducted a ~20 peer review of a studies of future vehicle technology used in making policy decisions for future fuel-economy regulations.

NHTSA Automotive Technology/Policy Report Reviewer 2014
Peer Reviewer

- Conducted a ~30 peer review of a studies of future vehicle technology used in making policy decisions for future fuel-economy regulations.

EcoCAR 2 Faculty Advisory Board
Board Member 2013-14

- Work with Department of Energy staff, Argonne National Labs Staff, General Motors staff, and four other EcoCAR faculty advisors to improve the student design experience for the EcoCAR program

Clean Fuels Ohio, Columbus, OH 2009-13
Member of the Board of Directors

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

EPA Automotive Technology Policy Report Reviewer
Peer Reviewer 2012

- Conducted a ~30 hour peer review of a study of future light-duty vehicle technology used in making policy decisions for future fuel-economy regulations.

EcoCAR 2 Faculty Advisory Board
Board Member 2011-12

- Work with Department of Energy staff, Argonne National Labs Staff, General Motors staff, and four other EcoCAR faculty advisors to improve the student design experience for the EcoCAR program

EPA Light-Duty Vehicle Model Reviewer
Peer Reviewer 2011
- Conducted a ~30 hour peer review of a study of future light-duty vehicles for the U.S. EPA used for guiding future fuel economy and greenhouse gas emissions regulations

EPA GEM Model Reviewer
Peer Reviewer 2010
- Conducted a ~20 hour peer review of a heavy-duty truck model developed by the U.S. EPA used for predicting fuel economy and greenhouse gas emissions

State of Indiana 2009
Proposal Reviewer
- Reviewed multi-million dollar proposal for Indiana grant program in area of internal combustion engines

Conference and Session Organization:

NAFEMS 2019 Session Chair 2019
- Organized session focused on modeling and simulation education

E^{3}COSM 2015 Co-Chair 2015
- Worked with Chair (Giorgio Rizzoni) to host major conference at Ohio State University

Journal / Conference Publication Reviewer:

Dr. Midlam-Mohler is a reviewer for the following publications / conferences:

1. International Journal of Vehicle Design
2. International Journal of Powertrains
3. Society of Automotive Engineers World Congress
4. American Society of Mechanical Engineers - Dynamic Systems and Control Conference
5. Institute of Electrical and Electronics Engineers – American Controls Conference
6. Institute of Electrical and Electronics Engineers - Conference on Decision and Control
7. Institute of Electrical and Electronics Engineers - Transactions on Automatic Control
8. Institute of Electrical and Electronics Engineers - Transactions on Power Systems

Professional Society Membership:

- ASME
- IEEE
- SAE

SCHOLARSHIP

Dr. Midlam-Mohler maintains an active research program and has been awarded more than $10 million in research funding. He has 1200+ citations and an h-index of 19 via Google Scholar and 650+ citations and an h-index of 14 via SCOPUS. He has more than 100 peer-reviewed conference publications, journal publications, and issued US patents assigned to industry. He has been PI or co-PI on five projects which have generated intellectual property royalties via trade secret generation.

Research Grants/Funding:

Dr. Midlam-Mohler was PI or co-PI on the following research projects:

Start	Duration	Sponsor	Project Title

Date	(Years)		
8/2005	1.9	Tenneco Automotive	Diesel Particulate Filter Regeneration with External Burner
9/2005	3.3	Tenneco Automotive	Reductant Generation for NOx Remediation
3/2007	0.8	Tenneco Automotive	Heavy-Duty Burner Prototypes and Control Development
3/2007	3.8	General Motors Corp	Development and Implementation of a Methodology, Processes, and Tools to Produce a Hierarchy of Powertrain Models that Enable a Math-Based Virtual Design Environment for Powertrain Control
9/2007	1.6	Nat Energy Tech Lab	Design and Fabrication of Diesel Fuel Atomizers
1/2008	2.0	Tenneco Automotive	Non-Catalytic Reformer Sensitivity Study and Prototype Development
4/2008	4.0	Cummins, Inc	Diesel Engine Combustion Control
9/2008	3.0	Department of Energy / General Motors	EcoCAR 1 Advanced Technology Vehicle Competition
1/2009	3.0	CAR PHEV Consortium	Fleet Studies and Transformer Modeling of PHEVs
4/2009	2.3	FirmGreen, Inc.	Landfill Gas Derived CNG Fuel Cycle Analysis
4/2009	3.4	Cummins, Inc	Cummins CIDI Engine Variability Measurements
4/2009	2.5	Stoneridge	Soot Sensor Testing and Soot Sensor Test Fixture
9/2009	1.3	Henkel Corp	Combustion Chamber Coating Evaluation
5/2010	3.8	Chrysler Group LLC	Advanced Technology Powertrains for Light-Duty Vehicles
10/2010	2.0	CAR Industrial Consortium	Lubricant Effects on Advanced Technology Vehicles
8/2011	3.0	Stoneridge	Fundamental Electrical Properties of Diesel Soot Films on a Diesel Soot Sensor
9/2011	3.0	Department of Energy / General Motors	EcoCAR 2 Advanced Technology Vehicle Competition
8/2012	2.0	Ctr for Trans. & Environment	ECO Saver IV Hybrid Electric Fuel Cell Bus Demonstration
10/2012	2.0	CAR Industrial Consortium	Gasoline Engine Particulate Matter Control
1/2013	0.3	Honda R&D Americas	Automated Vehicle Control Using Low-Cost Sensors
7/2013	0.5	American Electric Power	Plug-In Electric Vehicle Data Analyses, Insights and Reports
12/2013	2.0	Chrysler Group LLC	Model-Based Optimization and Control Methodology for the Design of Chrysler's Next Generation Powertrain Control Systems
9/2014	2.0	Honda R&D Americas	Engine Startability Simulation, Modeling, and Control
9/2014	2.0	Honda R&D Americas	Model-Based Engine Calibration Techniques
9/2014	1.5	CAR Industrial Consortium	HIL Capabilities Development
9/2014	1.5	CAR Industrial Consortium	Flexible Engine ECU Development
9/2014	2.0	Chrysler Group LLC	Model-Based Particulate Filter Diagnosis and Control

9/2014	4	Department of Energy / General Motors	EcoCAR 3 Advanced Technology Vehicle Competition
6/2015	0.3	Harley-Davidson Motorcycles	Development of a Post-Catalyst Air-to-Fuel Ratio Controller
10/2015	2	General Motors	Engine Calibration Using Eigenvariables
9/2016	2	Honda R&D Americas	APEX Phase I – 2030 Concept Vehicle R&D
9/2016	3	Honda R&D Americas	1D and 3D Model-Based Engine Design Techniques
9/2016	1.3	Honda R&D Americas	0D Tool Development to Improve Combustion Modeling Performance
10/2016	0.3	Schaeffler Group USA Inc.	Trailer Sway Vehicle Dynamics and Control
11/2016	0.3	Harley-Davidson Motorcycles	Fuel and Air Dynamics Modeling and Compensation for PFI IC Engines
6/2017	3	Honda R&D Americas	Traffic System Modeling for ADAS/Autonomous Vehicles
9/2017	1.5	GE Appliance	Model-Based Heat Flux Sensor Development
10/2017	1.5	Honda R&D Americas	Transmission Modeling for xIL Simulation
12/2017	.75	Honda R&D Americas	Powertrain Optimization for the APEX Autonomous Vehicle
12/2017	.75	Honda R&D Americas	Structural Optimization for the APEX Autonomous Vehicle
6/2018	3	Ford / Honda	Virtual V/V of Autonomous Vehicle Software for Safety
6/2018	2	Trans. Res. Center (TRC)	Development of Virtual Test Cases for AV Safety
9/2018	4	Department of Energy / General Motors	EcoCAR Mobility Challenge
6/2019	.5	Honda R&D Americas	Human-Centric Metrics of ADAS Vehicle Drive Quality
8/2019	.5	Honda R&D Americas	3D Modeling of GDI Combustion
9/2019	.5	NHTSA-VRTC	Evaluation of Open Source Standards for Autonomous Vehicle Test Case Creation
6/2020	.75	Air Force Research Lab / Perduco	Convergence Criteria Development and Application AFSIM Scenarios
8/2020	3	Department of Energy	Simulation-Driven Design Optimization and Automation for Cordwood-Fueled Room Heaters
9/2020	3	Department of Energy	NEXTCAR 2 Program

Journal Publications – Published:

Individuals who were advised/mentored/supervised by Dr. Midlam-Mohler are denoted via gray highlighting.

1. Pérez W, Tulpule P, Midlam-Mohler S, Rizzoni G. Data-Driven Adaptive Equivalent Consumption Minimization Strategy for Hybrid Electric and Connected Vehicles. Applied Sciences. 2022; 12(5):2705. https://doi.org/10.3390/app12052705.
2. Zhu Z, Midlam-Mohler S, Canova M. Development of physics-based three-way catalytic converter model for real-time distributed temperature prediction using proper orthogonal decomposition and collocation. International Journal of Engine Research. 2021;22(3):873-889. doi:10.1177/1468087419876127

3. Zhaoxuan Zhu, Shawn Midlam-Mohler, Marcello Canova. "Development of physics-based three-way catalytic converter model for real-time distributed temperature prediction using proper orthogonal decomposition and collocation", *International Journal of Engine Research*, 2019.
4. Gong, Qiuming, Shawn Midlam-Mohler, Emmanuele Serra, Vincenzo Marano, and Giorgio Rizzoni. "PEV Charging Control Considering Transformer Life and Experimental Validation of a 25 kVA Distribution Transformer." *Smart Grid, IEEE Transactions on 6*, no. 2: 648-656. 2015.
5. Hyde, A., Midlam-Mohler, S., and Rizzoni, G., "Development of a Dynamic Driveline Model for a Parallel-Series PHEV," SAE Int. J. Alt. Power. 3(2):244-256, 2014, doi: 10.4271/2014-01-1920. 2014.
6. Rajagopalan, S. S., Midlam-Mohler, S., Yurkovich, S., Dudek, K. P., Guezennec, Y. G., & Meyer, J. "A control design and calibration reduction methodology for AFR control in gasoline engines", Control Engineering Practice, 27, 42-53. 2014.
7. Bovee, K.; Hyde, A.; Midlam-Mohler, S.; Rizzoni, G.; Yard, M.; Trippel, T. et al. "Design of a Parallel-Series PHEV for the EcoCAR 2 Competition." *SAE International Journal of Fuels and Lubricants, 5* (3). 1317-1344. doi:10.4271/2012-01-1762. 2012.
8. Gong, Q.; Midlam-Mohler, S.; Marano, V.; Rizzoni, G. "PEV Charging Impact to the Distribution Transformer Life." *IEEE Transactions on Smartgrid, 3*. 2012.
9. Q. Gong, S. Midlam-Mohler, V. Marano, G. Rizzoni, "Statistical Analysis for PHEV Virtual Fleet Study", International Journal of Vehicle Design, Vol. 58, Nos. 2/3/4, 2012.
10. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, and Giorgio Rizzoni. "Virtual PHEV fleet study based on Monte Carlo simulation." *International Journal of Vehicle Design* 58, no. 2–4 (2012): 266–290. doi:10.1504/IJVD. 047388. 2012.
11. B. Cooley, D. Vezza, S. Midlam-Mohler, G. Rizzoni, "Model Based Engine Control Development and Hardware-in-the-Loop Testing for the EcoCAR Advanced Vehicle Competition", SAE International Journal on Engines, Vol. 4, No. 1, pp. 1699 -1707, 2011.
12. Meyer, Jason A; Yurkovich, Stephen; Midlam-Mohler, Shawn. "A Model Based Estimator for Cylinder Specific Air-to-Fuel Ratio Corrections." JOURNAL OF DYNAMIC SYSTEMS MEASUREMENT AND CONTROL-TRANSACTIONS OF THE ASME. Vol. 133, no. 3. : 031001. 2011.
13. Q. Gong, S. Midlam-Mohler, V. Marano, G. Rizzoni, "An Iterative Markov Chain Approach for Generating Vehicle Drive Cycles", SAE International Journal on Engines, Vol. 4, No. 1, pp. 1035-1045, 2011.
14. M. Canova, S. Midlam-Mohler, P. Pisu, A. Soliman, "Model-Based Fault Detection and Isolation for a Diesel Lean NOx Trap Aftertreatment System," Control Engineering Practice, November 2009.
15. M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Mean Value Modeling and Analysis of HCCI Diesel Engines with External Mixture Formation," ASME Journal of Dynamic Systems, Measurement and Control, Vol. 131, No. 11, 2009.
16. M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, "Theoretical and Experimental Investigation on Diesel HCCI Combustion with External Mixture Preparation," International Journal of Vehicle Dynamics, Volume 44, Nos 1-2, 2007.
17. N. Szabo, C. Lee, J. Trimboli1, O. Figueroa, R. Ramamoorthy, S. Midlam-Mohler, A. Soliman, H. Verweij, P. Dutta and S. Akbar, "Ceramic-Based Chemical Sensors, Probes and Field-Tests in Automobile Engines," Journal of Materials Science, November, 2003.

Peer-Reviewed Conference Papers:

All of the following conference publications included presentations by Dr. Midlam-Mohler or one of the co-authors. Individuals who were advised/mentored/supervised by Dr. Midlam-Mohler are denoted via gray highlighting.

1. Singh, H., Midlam-Mohler, S., & Tulpule, P. (2021). Simulation based virtual testing for safety of ADAS algorithms-case studies. SAE Technical Paper.
2. Bithar, V., Tulpule, P., & Midlam-Mohler, S. (2021). Online Robust MPC based Emergency Maneuvering System for Autonomous Vehicles. ArXiv Preprint ArXiv:2109.11959.
3. Tulpule, P., Midlam-Mohler, S., Karumanchi, A., & Jin, Y. (2021). A Simulation Tool for Virtual Validation and Verification of Advanced Driver Assistance Systems. SAE Technical Paper.
4. Patil, M., Lybarger, A., Midlam-Mohler, S., & Stoddart, E. (2021). Driving Automation System Test Scenario Development Process Creation and Software-in-the-Loop Implementation. SAE Technical Paper.

5. Kristina Kuwabara, Jacqueline Karl-DeFrain, Shawn Midlam-Mohler, Mahaveer Kantilal Satra, Akshra Narasimhan Ramakrishnan. "Model-Based Design of a Hybrid Powertrain Architecture with Connected and Automated Technologies for Fuel Economy Improvements", SAE 2020-01-1438.
6. Stoddart, E., Chebolu, S., and Midlam-Mohler, S., "System Engineering of an Advanced Driver Assistance System," SAE Technical Paper 2019-01-0876, 2019. [Student Presented at Conference]
7. Trask, S., Stewart, M., Kerwin, T., and Midlam-Mohler, S., "Effectiveness of Warning Signals in Semi-Autonomous Vehicles," SAE Technical Paper 2019-01-1013, 2019. [Student Presented at Conference]
8. Thomas, C., Tulpule, P., and Midlam-Mohler, S., "Model Order Reduction for x-In the Loop (xIL) Simulation of Automotive Transmissions," SAE Technical Paper 2019-01-1042, 2019. [Student Presented at Conference]
9. Z Zhu, M Canova, S Midlam-Mohler, "A Physics-Based Three-Way Catalytic Converter Model for Real-Time Prediction of Temperature Distribution", International Conference on Automotive Control, 2018.
10. Kibalama, Dennis, et al. Testing and Validation of a Belted Alternator System for a Post-Transmission Parallel PHEV for the EcoCAR 3 Competition. No. 2017-01-1263. SAE Technical Paper, 2017. [Student Presented at Conference]
11. Tulpule, Punit, et al. "Model Based Design (MBD) and Hardware In the Loop (HIL) validation: Curriculum development." American Control Conference (ACC), 2017. IEEE, 2017.
12. Guercioni, G. R., Vigliani, A., Galvagno, E., & Midlam-Mohler, S., "Gearshift control for hybrid powertrains with AMTs." Electrical and Electronic Technologies for Automotive, 2017 International Conference of. IEEE, 2017. [Student Presented at Conference]
13. Yacinthe, S., Khanna, A., Ward, J., Yatsko, M., Midlam-Mohler, S. Development of the Design of a Plug-in Hybrid-Electric Vehicle for the EcoCAR 3. No. 2016-01-1257. SAE Technical Paper, 2016. [Student Presented at Conference]
14. Khanna, A., Yacinthe, S., Ward, J., Yatsko M., Midlam-Mohler., S. *Model and Controls Development of a Post-Transmission PHEV for the EcoCAR 3 Competition*. No. 2016-01-1252. SAE Technical Paper, 2016. [Student Presented at Conference]
15. Midlam-Mohler, S., Linger, J., & Slavinski, J., & Fiorentini, L. *Project Management Inside and Outside of the Curriculum at the Ohio State University*. ASEE Annual Conference and Exposition, Seattle, Washington. 10.18260/p.24600, 2015. [Student Presented at Conference]
16. Bovee, Katherine, Amanda Hyde, Margaret Yatsko, Matthew Yard, Matthew Organiscak, Bharatkumar Hegde, Jason Ward, Andrew Garcia, Shawn Midlam-Mohler, and Giorgio Rizzoni. *Plant Modeling and Software Verification for a Plug-in Hybrid Electric Vehicle in the EcoCAR 2 Competition*. No. 2015-01-1229. SAE Technical Paper, 2015. [Student Presented at Conference]
17. Hegde, Bharatkumar, Shawn Midlam-Mohler, and Punit J. Tulpule. "Thermal Model of Fuse Dynamics for Simulation Under Intermittent DC Faults." In *ASME 2015 Dynamic Systems and Control Conference*, pp. V002T34A008-V002T34A008. American Society of Mechanical Engineers, 2015. [Student Presented at Conference]
18. Bovee, K., Rizzoni, G.; Midlam-Mohler, S.; Yard, M.; Yatsko, M.J. *Well-to-wheel analysis and measurement of energy use and greenhouse gas and criteria emissions in a Plug-in Hybrid Vehicle: The EcoCAR 2 case study*, 2015. [Student Presented at Conference]
19. Bovee, K., Hyde, A., Yatsko, M., Yard, M., Organiscak, M., Gallo, E. ... & Midlam-Mohler, S. W., "Refinement of a Parallel-Series PHEV for Year 3 of the EcoCAR 2 Competition", SAE Technical Paper 2014-01-2908, 2014. [Student Presented at Conference]
20. Alley, Robert Jesse, Patrick Walsh, Nicole Lambiase, Brian Benoy, Kristen De La Rosa, Douglas Nelson, Shawn Midlam-Mohler, Jerry Ku, and Brian Fabien. "ESS Design Process Overview and Key Outcomes of Year Two of EcoCAR 2: Plugging in to the Future." SAE Technical Paper, 2014.
21. Hyde, Amanda, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Development of a Dynamic Driveline Model for a Parallel-Series PHEV," SAE Technical Paper, 2014. [Student Presented at Conference]
22. Bovee, K., Hyde, A., Yard, M., Gallo, E., Garcia, A., Organiscak, M., Midlam-Mohler, S. W. & Rizzoni, G., "Fabrication of a Parallel-Series PHEV for the EcoCAR 2 Competition" ,SAE Technical Paper 2013-01-2491, 2013. [Student Presented at Conference]
23. Gong, Q., S. Midlam-Mohler, E. Serra, V. Marano, and G. Rizzoni. "PEV charging control for a parking lot based on queuing theory." In *American Control Conference (ACC), 2013*, pp. 1124-1129. IEEE, 2013. [Student Presented at Conference]
24. Meyer, Jason, Stephen Yurkovich, and Shawn Midlam-Mohler. "Air-to-Fuel Ratio Switching Frequency Control for Gasoline Engines." In *Control Systems Technology, IEEE Transactions on*, 21:636–48, 2013. [Student Presented at Conference]

25. Bezaire, Beth, and Shawn Midlam-Mohler. "A Physically-Based, Lumped-Parameter Model of an Electrically-Heated Three-Way Catalytic Converter." SAE Technical Paper, 2012. [Student Presented at Conference]
26. Bovee, Katherine, Amanda Hyde, Shawn Midlam-Mohler, Giorgio Rizzoni, Matthew Yard, Travis Trippel, Matthew Organiscak, et al. "Design of a Parallel-Series PHEV for the EcoCAR 2 Competition." SAE Technical Paper, 2012. [Student Presented at Conference]
27. Bovee, Katherine, Amanda Hyde, Travis Trippel, Vignesh Vimalesan, Sabarish Gurusubramanian, Kishore Kumaraswamy Sai, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Rapid Vehicle Architecture Selection With Use of Autonomie." In *ASME 2012 5th Annual Dynamic Systems and Control Conference Joint with the JSME 2012 11th Motion and Vibration Conference*, 119–28. American Society of Mechanical Engineers, 2012. [Student Presented at Conference]
28. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, and Giorgio Rizzoni. "Study of PEV Charging on Residential Distribution Transformer Life." In *Smart Grid, IEEE Transactions on*, 3:404–12, 2012.
29. Gong, Q., S. Midlam-Mohler, V. Marano, and G. Rizzoni. "Distribution of PEV Charging Resources to Balance Transformer Life and Customer Satisfaction." In *Electric Vehicle Conference (IEVC), 2012 IEEE International*, 1–7. IEEE, 2012. [Student Presented at Conference]
30. Gong, Q., S. Midlam-Mohler, E. Serra, V. Marano, and G. Rizzoni. "Distribution Transformer Tests for PEV Smart Charging Control." In *Energytech, 2012 IEEE*, 1–6. IEEE, 2012. [Student Presented at Conference]
31. Skarke, Philipp, Shawn Midlam-Mohler, and Marcello Canova. "Waste Heat Recovery From Internal Combustion Engines: Feasibility Study on an Organic Rankine Cycle With Application to the Ohio State EcoCAR PHEV." In *ASME 2012 Internal Combustion Engine Division Fall Technical Conference*, 609–15. American Society of Mechanical Engineers, 2012.
32. Q. Gong, S. Midlam-Mohler, V. Marano, G. Rizzoni, "Optimal Control of PEV Charging Based on Residential Base Load Prediction", ASME Dynamic Systems and Control Conference (DSCC), 2011. [Student Presented at Conference]
33. J. Meyer, S. Midlam-Mohler, S. Yurkovich, "In-cylinder Oxygen Concentration Estimation for Diesel Engines Via Transport Delay", American Control Conference, 2011. [Student Presented at Conference]
34. K. Follen, M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, B. Lee, G. Matthews, "A High Fidelity Lumped-Parameter Engine Model for Powertrain Control Design and Validation.", ASME Dynamic Systems and Control Conference, Cambridge, MA, United States, 2011. [Student Presented at Conference]
35. Cooley, Robert, Davide Vezza, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Model Based Engine Control Development and Hardware-in-the-Loop Testing for the EcoCAR Advanced Vehicle Competition." SAE Technical Paper, 2011. [Student Presented at Conference]
36. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, and Giorgio Rizzoni. "An Iterative Markov Chain Approach for Generating Vehicle Driving Cycles." SAE Technical Paper, 2011.
37. Gong, Q., S. Midlam-Mohler, V. Marano, and G. Rizzoni. "PEV Charging Impact on Residential Distribution Transformer Life." In *Energytech, 2011 IEEE*, 1–6. IEEE, 2011. [Student Presented at Conference]
38. Gong, Q., P. Tulpule, V. Marano, S. Midlam-Mohler, and G. Rizzoni. "The Role of ITS in PHEV Performance Improvement." In *American Control Conference (ACC), 2011*, 2119–24. IEEE, 2011.
39. Marano, V., P. Tulpule, Q. Gong, A. Martinez, S. Midlam-Mohler, and G. Rizzoni. "Vehicle Electrification: Implications on Generation and Distribution Network." In *Electrical Machines and Systems (ICEMS), 2011 International Conference on*, 1–6. IEEE, 2011.
40. Meyer, Jason, Shawn Midlam-Mohler, and Stephen Yurkovich. "In-Cylinder Oxygen Concentration Estimation for Diesel Engines via Transport Delay Modeling." In *American Control Conference (ACC), 2011*, 396–401. IEEE, 2011. [Student Presented at Conference]
41. Bayar, Kerem, Beth Bezaire, Brad Cooley, John Kruckenberg, Eric Schacht, Shawn Midlam-Mohler, and Giorgio Rizzoni. "Design of an Extended-Range Electric Vehicle for the EcoCAR Challenge." In *ASME 2010 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 687–700. American Society of Mechanical Engineers, 2010. [Student Presented at Conference]
42. Follen, K., M. Canova, S. Midlam-Mohler, Y. Guezennec, G. Rizzoni, B. Lee, and G. Matthews. "A High Fidelity Lumped-Parameter Engine Model for Powertrain Control Design and Validation." In *ASME 2010 Dynamic Systems and Control Conference*, 695–702. American Society of Mechanical Engineers, 2010.
43. Gong, Qiuming, Shawn Midlam-Mohler, Vincenzo Marano, Giorgio Rizzoni, and Yann Guezennec. "Statistical Analysis of Phev Fleet Data." In *Vehicle Power and Propulsion Conference (VPPC), 2010 IEEE*, 1–6. IEEE, 2010.
44. Meyer, Jason, Stephen Yurkovich, and Shawn Midlam-Mohler. "Architectures for Phase Variation Compensation in AFR Control." In *American Control Conference (ACC), 2010*, 1447–52. IEEE, 2010.

45. R. Maringanti, S. Midlam-Mohler, M. Fang, F. Chiara, M. Canova, "Set-Point Generation using Kernel-Based Methods for Closed-Loop Combustion Control of a CIDI Engine," ASME DSCC2009, September, 2009.
46. J. Meyer, S. Rajagopalan, S. Midlam-Mohler, Y. Guezennec, S. Yurkovich, "Application of an Exhaust Geometry Based Delay Prediction Modal to an Internal Combustion Engine," ASME DSCC2009, September, 2009.
47. M. Fang, S. Midlam-Mohler, R. Maringanti, F. Chiara, M. Canova, "Optimal Performance of Cylinder-by-Cylinder and Fuel Bank Controllers for a CIDI Engine," ASME DSCC2009, September, 2009.
48. S. Midlam-Mohler, E. Marano, S. Ewing, D. Ortiz, G. Rizzoni, "PHEV Fleet Data Collection and Analysis," IEEE VPPC09, 2009.
49. L. Headings, G. Washington, S. Midlam-Mohler, J. Heremans, "Thermoelectric Power Generation for Hybrid-Electric Vehicle Auxiliary Power," Proc. SPIE Int. Conference on Smart Structures and Materials, Vol. 7290, No. 13, 2009.
50. L. Headings, G. Washington, S. Midlam-Mohler, and J. Heremans, "High temperature multi-fuel combustion-powered thermoelectric auxiliary power unit", Proceedings of SMASIS2009: ASME 2009 Conference on Smart Materials, Adaptive Structures and Intelligent Systems, Oxnard, CA, USA, ASME, 123-130, 2009.
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53. S. Rajagopalan, S. Midlam-Mohler, S. Yurkovich, Y. Guezennec, K. Dudek, "Control Oriented Modeling of a Three Way Catalyst Coupled with Oxygen Sensors," ASME Dynamic System and Controls Conference, Ann Arbor, MI, 2008.
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55. K. Sevel, M. Arnett, K. Koprubasi, C. Coburn, M. Shakiba-Heref, K. Bayar, G. Rizzoni, Y. Guezennec, S. Midlam-Mohler, "Cleaner Diesel Using Model-Based Design and Advanced Aftertreatment," SAE 2008-01-0868, 2008 International Congress, Detroit, MI, April 2008.
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74. C. Musardo, B. Staccia, S. Midlam-Mohler, Y. Guezennec, and G. Rizzoni, "Supervisory Control for NOX Reduction of an HEV with a Mixed-Mode HCCI/CIDI Engine," American Control Conference '05, Portland, OR, June 2005.
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76. S. Midlam-Mohler, S. Haas, Y. Guezennec, M. Bargende, G. Rizzoni, S. Haas, and H. Berner, "Mixed-Mode Diesel HCCI/DI with External Mixture Preparation," Paper F2004V258, Proc. FISITA '04 World Congress, Barcelona, Spain, May 2004.
77. Y. Guezennec, C. Musardo, B. Staccia, S. Midlam-Mohler, E. Calo, P. Pisu, and G. Rizzoni, "Supervisory Control for NOx Reduction of an HEV with a Mixed-Mode HCCI/DI Engine," Paper F2004F233, Proc. FISITA '04 World Congress, Barcelona, Spain, May 2004.
78. M. Gilstrap, G. Anceau, C. Hubert, M. Keener, S. Midlam-Mohler, K. Stockmeier, J-M Vespasien, Y. Guezennec, F. Ohlemacher, and G. Rizzoni, "The 2002 Ohio State University FutureTruck – The BuckHybrid002," 2003 SAE International Congress and Exposition, Detroit, MI, March 2003.
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Patents:

In addition to the following patents, Dr. Midlam-Mohler has a number of trade secrets in use in industry around control algorithms or processes. Industry often chooses not to patent these as it offers greater protection because of the difficulty in enforcement.

1. S. Midlam-Mohler, J. Meyer, S. Yurkovich, V. Sujan, "Combustion controller for internal combustion engine", US Patent 9,353,696, issued May 31, 2016.
2. Rajagopalan, Sai SV, Kenneth P. Dudek, Sharon Liu, Stephen Yurkovich, Shawn W. Midlam-Mohler, Yann G. Guezennec, and Yiran Hu. "Universal tracking air-fuel regulator for internal combustion engines." U.S. Patent 8,571,785, issued October 29, 2013.
3. J. Meyer, S. Midlam-Mohler, K. Dudek, S. Yurkovich, Y. Guezennec, "Fuel control system and method for more accurate response to feedback from an exhaust system with an air/fuel equivalence ratio offset", U.S. Patent 8,347,866, awarded January 8, 2013.
4. S. Midlam-Mohler, S. Rajagoplan, K. Dudek, S. Yurkovich, Y. Guezennec, "Compensating for random catalyst behavior", 8,346,458, January 1, 2013.

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

Intellectual Property Royalties:

The following five research projects involved royalty payments to OSU for exclusive rights to IP from the research project. None of these projects resulted in patents, instead, the company uses the IP as a trade secret.

1. Model-based optimization and control methodology for the design of Chrysler's next generation powertrain control systems, 12/01/2013 - 11/30/2015, Co-PI
2. Model-Based Gasoline Particulate Filter System Design, Control, And Diagnosis 07/01/2014 - 07/15/2016, Sole PI
3. Engine Startability Simulation, Modeling, And Control 09/01/2014 - 02/28/2017, Sole PI
4. Engine Calibration Using Eigenvariables, 10/15/2014 - 09/15/2016, Lead PI
5. Model-Based Heat Flux Sensor Development, 09/01/2017 - 12/31/2018, Lead PI

Applied R&D Projects Judged in Juried Competitions:

The following table contains awards earned by the EcoCAR team which Dr. Midlam-Mohler advises. Entry into the competition is competitive and has included many well-regraded engineering schools.. Awards are decided by either quantitative evaluation of vehicle performance or via qualitative assessment by panels of ~6 to ~12 experts from industry, the Department of Energy, and Argonne National Lab.

EcoCAR Mobility Challenge 2020
Competition Sponsors: U.S. Department of Energy, General Motors, and The Mathworks

1. 1st Place Subsystem Design Report
2. Best Final Technical Report
3. Best Human-Machine Interface and User Interface Video
4. Best Execution Plan
5. Best Impact Report
6. Women in STEM Award to Team Member Kristina Kuwabara
7. Note: Due to Covid-19, there was no overall winner in this competition year

EcoCAR Mobility Challenge 2019
Competition Sponsors: U.S. Department of Energy, General Motors, and The Mathworks

8. 1st Place Overall
9. 1st place: Target Market Presentation
10. 1st place: Controls and Systems Modeling & Simulation Presentation
11. 2nd place: Connected and Automated Vehicle Systems Presentation
12. 3rd place: Propulsion System Integration Presentation

13. Best Final Technical Report
14. 2nd Place in Connected and Automated Vehicle Systems Deliverables
15. 2nd Place: NSF Excellence in Connected and Automated Vehicles
16. 1st Place NSF Diversity in Engineering Award

EcoCAR 3 Competition 2018
Competition Sponsors: U.S. Department of Energy and General Motors

17. 1st Place Overall
18. Best Emissions Testing Event Performance
19. NSF Best Innovation Research Papers
20. 1st TRC Best Total Energy Consumption Award
21. 1st TRC Best Wheel-to-Well Petroleum Energy Usage
22. 1st Over the Road Event
23. 1st dSPACE Embedded Success Award
24. General Motors Women in Engineering Rookie Award
25. NSF Diversity in Engineering Award
26. 1st Vehicle Design Report
27. 1st Consumer Appeal
28. 1st Innovation Presentation
29. 2nd Control and SMS Presentation
30. 2nd Mechanical Presentation
31. 2nd Mathwork Modeling Award
32. 3rd ADAS Presentation

EcoCAR 3 Competition 2017
Competition Sponsors: U.S. Department of Energy and General Motors

33. Overall Competition, 1st Place
34. Overall Project Management, 1st Place
35. Vehicle Design Report, 1st Place
36. Project Status Presentation, 1st Place
37. Innovation Presentation, 3rd Place
38. Consumer Appeal Event, 2nd Place
39. ECE Presentation, 1st Place
40. Mechanical Presentation, 2nd Place
41. E&EC UFW Total Energy Consumption, 1st Place
42. E&EC UFW WTW Criteria Emissions, 1st Place
43. E&EC UFW WTW GHG Emissions, 1st Place
44. E&EC UFW WTW PEU, 1st Place

EcoCAR 3 Competition 2016
Competition Sponsors: U.S. Department of Energy and General Motors

45. Overall Competition, 1st Place
46. Overall Project Management, 2nd Place
47. Competition Project Status Presentation, 2nd Place
48. Controls Presentation, 1st Place
49. Electrical Presentation, 1st Place
50. Final Technical Report, 2nd Place
51. Mechanical Presentation, 2nd Place
52. Vehicle Design Report, 1st Place
53. Vehicle Design Review, 3rd Place
54. WW HIL Review, 1st Place

EcoCAR 3 Competition 2015
Competition Sponsors: U.S. Department of Energy and General Motors

55. 1st Place Overall
56. Best Final Stakeholder Status Presentation
57. Best Winter Workshop Innovation Topic Review
58. Best Innovation Presentation
59. Best Control Systems Presentation
60. Best Trade Show Presentation
61. SMS Presentation and Demonstration
62. Best Consumer Market Research Report
63. 2nd Place Project Management
64. dSPACE Embedded Success Award, 1st Place
65. MathWorks Modeling Award, 2nd Place

EcoCAR 2 Competition 2014
Competition Sponsors: U.S. Department of Energy and General Motors

66. 1st Place Overall
67. Lowest Petroleum Energy Use
68. Lowest Criteria Emissions
69. Best Final Technical Report
70. Best Static Consumer Acceptability
71. Best Controls Presentation
72. Best Electrical Presentation
73. Best Progress Reports
74. ETAS ECU Excellence Award, 1st Place
75. dSPACE Embedded Success Award, 1st Place
76. MathWorks Modeling Award, 2nd Place

EcoCAR 2 Competition 2013
Competition Sponsors: U.S. Department of Energy and General Motors

77. 3rd Place Overall
78. Best Final Technical Report
79. Best Electrical Presentation
80. Best Progress Reports
81. Women in Engineering Award
82. MathWorks Modeling Award, 2nd Place

EcoCAR 2 Competition 2012
Competition Sponsors: U.S. Department of Energy and General Motors

83. 2nd Place Overall
84. Best Winter Workshop Controller HIL Evaluation, 2nd Place
85. Best Project Initiation Approval Presentation, 2nd Place
86. Best Controls Presentation, 3rd Place
87. Best Final Controller HIL Evaluation, 1st Place
88. Best Trade Show Evaluation, 2nd Place
89. dSPACE Embedded Success Awards, 1st Place
90. MathWorks Modeling Award, 1st Place
91. Women in the Winner's Circle Foundation Women in Engineer Awards

EcoCAR Competition 2011
Competition Sponsors: U.S. Department of Energy and General Motors

92. 2nd Place Overall
93. Best Controls Presentation
94. Freescale Innovation Award
95. The MathWorks Modeling Award, 2nd Place
96. dSPACE Embedded Success Award, 2nd Place

97. BOSCH Diversity in Engineering Award, 1st Place

EcoCAR Competition 2010

Competition Sponsors: U.S. Department of Energy and General Motors

98. 5th Place Overall
99. HIL Evaluation Event, 1st Place
100. Dynamic Consumer Acceptability, 1st Place
101. Freescale Silicon on the Move Award
102. The MathWorks Modeling Award, 1st Place
103. dSPACE Embedded Success Award, 1st Place
104. BOSCH Diversity in Engineering Award, 3rd Place
105. Women in the Winner's Circle Foundation, Women in Engineering Award

EcoCAR Competition 2009

Competition Sponsors: U.S. Department of Energy and General Motors

106. 1st Place Overall
107. Best Written Design Report
108. HIL Evaluation Event, 1st Place
109. Controls Event Presentation, 1st Place
110. Best Trade Show Display and Presentation
111. Best Technical Success Story
112. Freescale Silicon on the Move Award, 3rd Place
113. dSPACE Embedded Success Award, 1st Place
114. BOSCH Diversity in Engineering Award, 1st Place

PERSONAL INFORMATION

Oscar Francisco Delgado Neira

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Oscar@theicct.org

http://www.theicct.org/staff/oscar-delgado

Sex Male | Date of birth 13/09/1979 | Nationality Colombian

JOB APPLIED FOR
POSITION
PREFERRED JOB
STUDIES APPLIED FOR

WORK EXPERIENCE

Zero-emission Fleets Center Manager and Latin America Lead

From 2020 – to present

- Co-lead of the Zero-Emission Bus Rapid-deployment Accelerator (ZEBRA) in Latin America
- Coordinate the Fleets Center, which concentrates ICCT's expertise, data, and tools to support Global commercial fleets in their transition to zero-emission vehicles.
- Support policymakers on the development of heavy-duty vehicle efficiency and emissions standards.

Business or sector Research, non-profit

Senior Researcher

International Council on Clean Transportation, Washington, DC. www.theicct.org

From 2016 – to 2020

- Project manager and/or principal investigator in heavy-duty vehicle efficiency technology related projects in the U.S, EU, China, India, and Latin America.
- Management of green freight and technology verification projects.
- Development of ICCT's vehicle simulation modelling capabilities.

Business or sector Research, non-profit.

Researcher

International Council on Clean Transportation, Washington, DC. www.theicct.org

From 2013 – to 2015

- Assessment of the potential for energy savings and GHG emissions reductions from heavy-duty vehicle efficiency technologies through modelling and simulation.
- Analysis of the cost-effectiveness of heavy-duty vehicle efficiency technologies
- Assessment of regulatory options for the second phase of US GHG heavy duty regulations.
- Analysis of potential scenarios on methane emissions and policy recommendations for heavy-duty natural gas vehicles
- Green freight and technology verification programs

Business or sector Research, non-profit.

europass Curriculum Vitae Oscar Delgado Neira

From 2010 – to 2012 **Visiting Instructor**

Mechanical and Aerospace Engineering Department. West Virginia University.

- Courses taught: Thermodynamics, Applied Thermodynamics, Fluids and Thermal laboratories.

Business or sector Academia

From 2008 – to 2012 **Graduate Research Assistant**

Center for Alternative Fuels, Engines, and Emissions. West Virginia University.

- Conducted research to assess the effects of road grade and vehicle weight in the fuel economy and emissions from heavy-duty vehicles using portable emissions measurements systems.
- Developed a modelling methodology to predict fuel consumption and pollutant emissions on the basis of chassis dynamometer measurements and driving cycle statistical parameters.
- Conducted a research program to model fuel consumption and emissions using neural networks, vehicle simulation software and linear modelling methodologies.
- Created test cycle development software to be used with in-use data gathered with GPS and on-board equipment.

Business or sector Research, academia.

From 2005 – to 2007 **Instructor**

Mechanical Engineering Department, Universidad de los Andes, Bogota, Colombia.

- Courses taught: Thermodynamics, Fluid Mechanics, Heat Transfer, Vector Mechanics, Dynamics, Experimentation Fundamentals, Technical Drawing, and Graphic Design in Engineering.

Business or sector Research, academia.

EDUCATION AND TRAINING

2007 - 2012 **Ph.D. Mechanical Engineering** Replace with EQF (or other) level if relevant

West Virginia University, Morgantown, WV, USA

- Engine testing, vehicle testing, vehicle simulation modelling.

2003 - 2005 **M.Sc. Mechanical Engineering**

Universidad de los Andes, Bogota, Colombia

- Polymer processing, thermal-fluid analysis, rheology.

1998 - 2003 **B.S. Mechanical Engineering**

Universidad de los Andes, Bogota, Colombia

- Minor: Business Administration

PERSONAL SKILLS

Mother tongue(s) Spanish

Other language(s)

	UNDERSTANDING		SPEAKING		WRITING
	Listening	Reading	Spoken interaction	Spoken production	
English	C2	C2	C2	C2	C2
	Replace with name of language certificate. Enter level if known.				
Portuguese	B1	C1	A1	A1	A1
	Replace with name of language certificate. Enter level if known.				

Levels: A1/2: Basic user - B1/2: Independent user - C1/2 Proficient user
Common European Framework of Reference for Languages

Communication skills

Good communication skills gained through my teaching and project management experience.

Computer skills

- Vehicle simulation modelling with MATLAB/Simulink/Stateflow, PSAT, Autonomie, GT-Power, VECTO, and GEM.
- Emissions inventory model analysis with VISION and MOVES.
- Knowledge of LabVIEW and data acquisition systems.
- Advanced data analysis with Matlab, Excel, and R.
- Computer aided design with Solid Edge, and Auto CAD.
- Computational fluid dynamics and thermal analysis with ANSYS CFX, Fluent, and EES.

Other skills

- Strong background and excellent record of teaching in thermal sciences, fluid mechanics, and vehicle emissions.
- Hands-on experience in emissions testing and vehicle efficiency monitoring.
- Analysis of emissions data from engine dynamometer, chassis dynamometer, and portable emissions measurement systems (PEMS).
- Self-motivated, detailed-oriented, team player.

ADDITIONAL INFORMATION

Publications

- Bueno C. and Delgado, O. (2022) "E-Bus fleet-wide deployment strategy for "Flota Nueva Villa" a bus operator in Medellin". International Council on Clean Transportation.
- Pineda, L., Jimenez, C., and Delgado, O. (2022) "E-bus fleet-wide deployment strategy for de public transport system of Mexico City "Metrobús": Bus lines 3 and 4. (In Spanish), International Council on Clean Transportation.
- Reboucas, A., Delgado, O., and Rozenfeld, T. (2022) "Analysis of the implementation of a zero-emission fleet for a bus operator in Sao Paulo" (In Portuguese). International Council on Clean Transportation
- Buysse, C., Sharpe, B., and Delgado, O. (2021) "Efficiency technology potential for heavy-duty diesel vehicles in the United States through 2035. International Council on Clean Transportation
- Dallman, T., Delgado, O., Jin, L., and Minjares, R. (2021) "Strategies for deploying zero-emission bus fleets: Route-level energy consumption and driving range analysis" International Council on Clean Transportation
- Jin, L., Delgado, O., Gadepalli, R., and Minjares, R. (2020) "Strategies for deploying zero-emission bus fleets: Development of real-world drive cycles to simulate zero-emission technologies along existing bus routes". International Council on Clean Transportation
- Delgado, O. (2020) "Technology and financing options to deploy zero-emission fleets in the public transport bus system in Medellin." International Council on Clean Transportation
- Yang, L., Delgado, O., and Muncrief, R. (2019) "Barriers and opportunities for improving long-haul freight efficiency in China" International Council on Clean Transportation

- Rodriguez, F., and Delgado, O. (2019) "The future of VECTO: CO2 certification of advanced heavy-duty vehicles in the European Union." International Council on Clean Transportation
- Sharpe, B., Delgado, O., Rodriguez, F., and Miller, J. (2019) "Adapting the Vehicle Energy Consumption Calculation Tool (VECTO) for use in India and other countries." International Council on Clean Transportation
- Delgado, O. and Rodriguez, F. (2019) "Comparison of aerodynamic drag determination procedures for HDV CO2 certification." International Council on Clean Transportation
- Posada, F., Miller, J., Delgado, O., and Minjares R. (2019) 2018 South America summit on vehicle emissions control: Summary report and regional workplan." International Council on Clean Transportation
- Delgado, O., Rodriguez, F., and Facanha, C. (2019) "Technology verification tool for green freight programs." International Council on Clean Transportation
- Meszler, D., Delgado, O., and Yang, L. (2019) "Heavy-duty vehicles in China: Cost-effectiveness of fuel-efficiency and CO2 reduction technologies for long-haul tractor-trailers in the 2025-2030 timeframe." International Council on Clean Transportation
- Rodriguez, F., Delgado, O., Demirgok, B., Baki, C., Besch, M., Thiruvengadam A., Rexeis, M., and Röck, M. (2019) "Heavy-duty aerodynamic testing for CO2 certification: A methodology comparison." SAE Technical Paper 2019-01-0649.
- Facanha, C., Delgado, O., and Yang, L. (2018) "China Green Freight Assessment. Enabling a cleaner and more efficient freight system in China." International Council on Clean Transportation
- Rodriguez, F and Delgado, O. (2018) "Recommendations for the proposed heavy-duty vehicle CO2 standards in the European Union." International Council on Clean Transportation
- Rodriguez, F., Delgado, O., and Muncrief, R. (2018) "Fuel consumption testing of tractor-trailers in the European Union and the United States." International Council on Clean Transportation
- Delgado, O. and Rodriguez, F. (2018) "CO2 emissions and fuel consumption standards for heavy-duty vehicles in the European Union." International Council on Clean Transportation
- Sharpe, B., Garg, M., and Delgado, O. (2018) "Fuel efficiency technology potential of HDVs between 3.5 and 12 tonnes in India." International Council on Clean Transportation
- Sharpe, B., Garg, M., and Delgado, O. (2018) "Compliance pathways in the U.S. Phase 2 heavy-duty vehicle efficiency regulation." International Council on Clean Transportation
- Meszler, D., Delgado, O., Rodriguez, F., and Muncrief, R. (2018) "European heavy-duty vehicles: Cost-effectiveness of fuel efficiency technologies for long-haul tractor-trailers in the 2025-2030 timeframe." International Council on Clean Transportation.
- Delgado, O., Rodriguez, F., and Muncrief, R. (2017) "Fuel efficiency technology in European heavy-duty vehicles: Baseline and potential for the 2020 - 2030 time frame." International Council on Clean Transportation.
- Delgado, O. and Li, H. (2017) "Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China." International Council on Clean Transportation.
- Zacharof, N., Fontaras, G., Grigoratos, T., Ciuffo, B., Savvidis, D., Delgado, O. and Rodriguez, F. (2017) "Estimating the CO_2 emissions reduction potential of various technologies in European trucks using VECTO simulator." SAE Technical Paper 2017-24-0018.
- Sharpe, B., Delgado, O., and Garg, M. (2017) "Fuel efficiency technology potential for on-road heavy-duty vehicles in India." SAE Technical Paper 2017-26-0145.
- Rodriguez, F., Muncrief, R., Delgado, O., Baldino, C. (2017) "Market penetration of fuel efficiency technologies for heavy-duty vehicles in the European Union, the United States, and China." International Council on Clean Transportation
- Kraal, N., Gopal, A., Sharpe, B., Delgado, O., Bandivadekar, A., and Garg, M. (2017) "Improved heavy-duty vehicle fuel efficiency in India. Benefits, costs and environmental impacts."
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ANNEXES

Appendix C: Conflict of Interest (COI) Forms

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer: U.S. Environmental Protection Agency

Contractor: ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031

Prime Contract: Task Order 68HERC22F0351 under Contract 68HERC21D0016

Subject Report: Peer Review of Electrified Vehicle Simulations within EPA's ALPHA Model

Subcontractor/Peer Reviewer: Sujit Das, Strategic Analysis, Inc.

In accordance with EPAAR 1552.209-70 through 1552.209-73, Subcontractor/Consultant certifies to the best of its knowledge and belief, that:

____X___ No actual or potential conflict of interest exists.

_______ An actual or potential conflict of interest exists. See attached full disclosure.

Subcontractor/Consultant certifies that its personnel, who perform work on this contract, have been informed of their obligations to report personal and organizational conflict of interest to Contractor and Subcontractor/Consultant recognizes its continuing obligation to identify and report any actual or potential organizational conflicts of interest arising during performance under referenced contract.

Sujit Das

____
Subcontractor/Consultant

____10/24/22___________________
Date

ICF

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer:	U.S. Environmental Protection Agency
Contractor:	ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031
Prime Contract:	Task Order 68HERC22F0351 under Contract 68HERC21D0016
Subject Report:	Peer Review of Electrified Vehicle Simulations within EPA's ALPHA Model
Subcontractor/Peer Reviewer:	Shawn Midlam-Mohler - ModelTek, LLC

In accordance with EPAAR 1552.209-70 through 1552.209-73, Subcontractor/Consultant certifies to the best of its knowledge and belief, that:

__X__ No actual or potential conflict of interest exists.

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____
Subcontractor/Consultant

11/7/22
Date

ORGANIZATIONAL CONFLICT OF INTEREST CERTIFICATE

Customer:	U.S. Environmental Protection Agency
Contractor:	ICF Incorporated, LLC, 9300 Lee Highway, Fairfax, VA 22031
Prime Contract:	Task Order 68HERC22F0351 under Contract 68HERC21D0016
Subject Report:	Peer Review of Electrified Vehicle Simulations within EPA's ALPHA Model
Subcontractor/Peer Reviewer:	International Council on Clean Transportation

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Oscar Delgado

Oscar Delgado, PhD
ICCT
Subcontractor/Consultant

10/28/2022
Date

Appendix D: Notes from Mid-review Teleconference

To: Jeff Cherry, TO COR, U.S. EPA

From: Sam Pournazeri, Project Manager, ICF

Date: October 6, 2022

Re: Peer Reviewers' Kick-off meeting for Task Order 68HERC22F0351 under Contract 68HERC21D0016 for Peer Review of Electrified Vehicle Simulations within EPA's ALPHA Model

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Meeting Date/Location

- **Date:** Thursday, October 6, 2022
- **Location:** Virtual using Microsoft Teams

Meeting Participants:

- Jeff Cherry, EPA, TO COR
- Brian Olson, EPA, Alternative TO COR
- Sam Pournazeri, ICF, Project Manager for the peer review
- Ramon Molina Garcia, ICF, Support staff for the peer review
- Oscar Delgado, Ph.D., International Council of Clean Transportation
- Shawn Midlam-Mohler, Ph.D., Professor, Ohio State University
- Sujit Das, Principal Engineer, Strategic Analysis Inc.

Meeting Minutes:

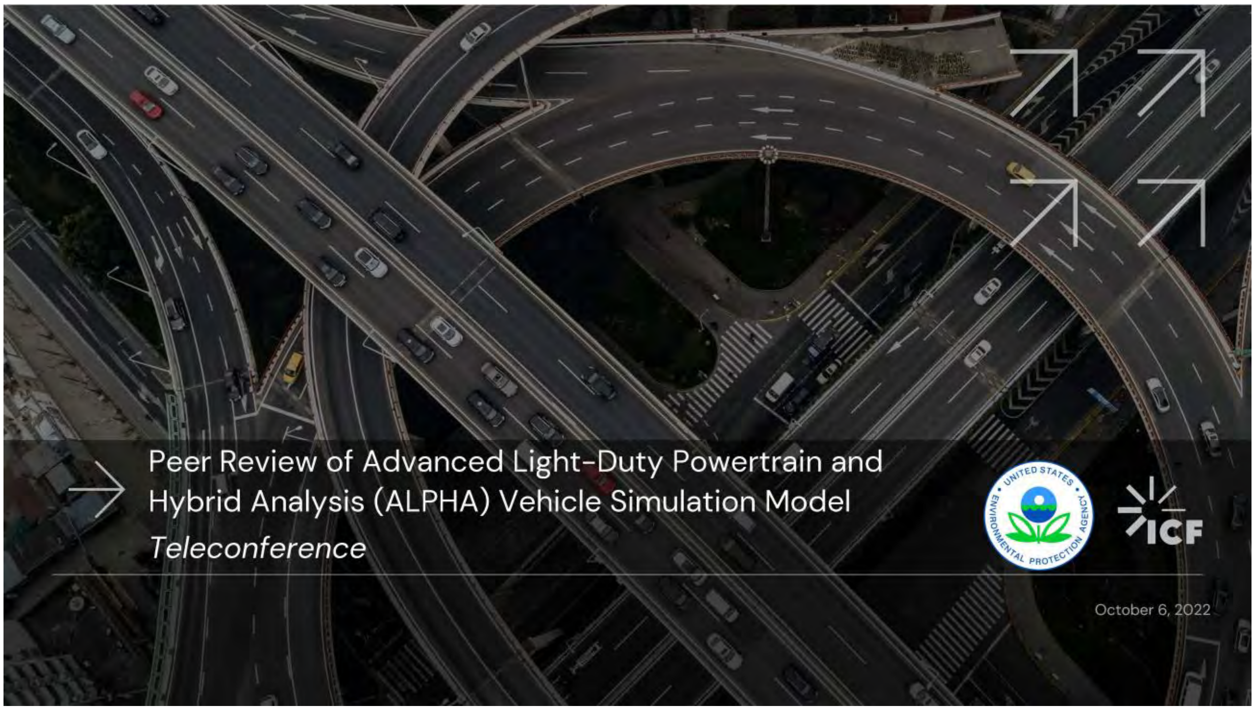
- Sam Pournazeri from ICF kicked off the meeting with a brief introduction
- Ramon Molina Garcia from ICF provided a slide presentation (appendix A) walking the peer reviewers through the process, charge questions, and timeline
- ICF, EPA staff, and peer reviewer panel introduced themselves.
- Jeff Cherry from EPA provided an overview of the model and gave some guidance to peer reviewers on the purpose of charge questions and that EPA is looking for peer reviewers to look at different aspects of the model.
- Peer reviewers asked a couple of questions regarding the areas where they should focus on.
- Sujit Das asked whether there is any other technical documentation aside from the one provided that shed light on the logics behind the model simulations where he can look and comment. He was concerned that the existing documentation mainly describes the codes and not the logic
- Jeff responded that there are several links provided under the Readme file that might be helpful and that the PDF documentation included in the zip folder should have sufficient information for the peer reviewers to comment on.

- Shawn Midlam-Mohler asked if there are more information available on some verification/validation data associated with the model and sub-models that are included in demo runs.
- Jeff recommended Shawn to send his questions through an email to ICF and for EPA to respond to them.
- Oscar Delgado from ICCT also asked whether EPA has validated the ALPHA tool results against real-world data or other commercially available vehicle simulation tools?
- Jeff recommended Oscar to send his questions through an email to ICF and for EPA to respond to them.
- Ramon continued the presentation by going over the materials provided, expected deliverables, and the timeline.
- At the end Sam mentioned that ICCT may need some extension on the peer review and Jeff confirmed that it is fine. Later after the meeting, Oscar mentioned that they will make sure to get their feedback back to ICF by October 28
- Both Shawn and Oscar submitted their questions through email, and Ramon forwarded those to EPA.

Next Steps:

- ICF will compile the reports from peer reviewers and submit those "as is" to EPA by November 2.
- ICF will prepare a technical process memo that describes how peer reviewers were selected, the process that ICF took to administer the peer review, and how the peer review was concluded. As part of this memo, ICF also include the unedited peer review comments and responses into a tabular format, with two columns as described above so that the individual comments may be easily grouped and compared for review purposes.
- Upon receiving the peer review reports from all reviewers, ICF will also start drafting the final report and deliver it to EPA two weeks after receipt of peer reviewers' comments.

ICF Slide Presentation



- Introductions
- EPA: Background of the Peer Review
- ICF: Peer Review Overview
  - Charge Questions
  - Materials to Review and Submit
  - Schedule
- Questions/Comments

Agenda

Introductions

ICF Team

- Sam Pournazeri, Ph.D., Director of Clean Transportation and Energy
- Ramon Molina Garcia, Transportation Specialist

EPA Team

- Jeff Cherry, TO COR, Office of Transportation and Air Quality
- Brian Olson, Alternative TO COR, Office of Transportation and Air Quality

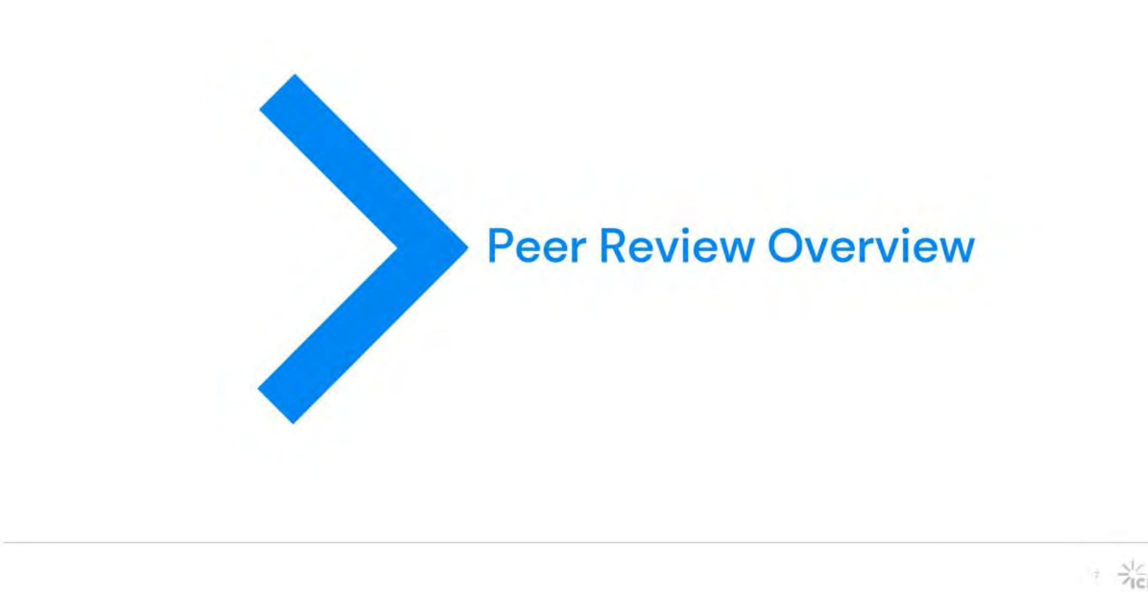
Peer Reviewers

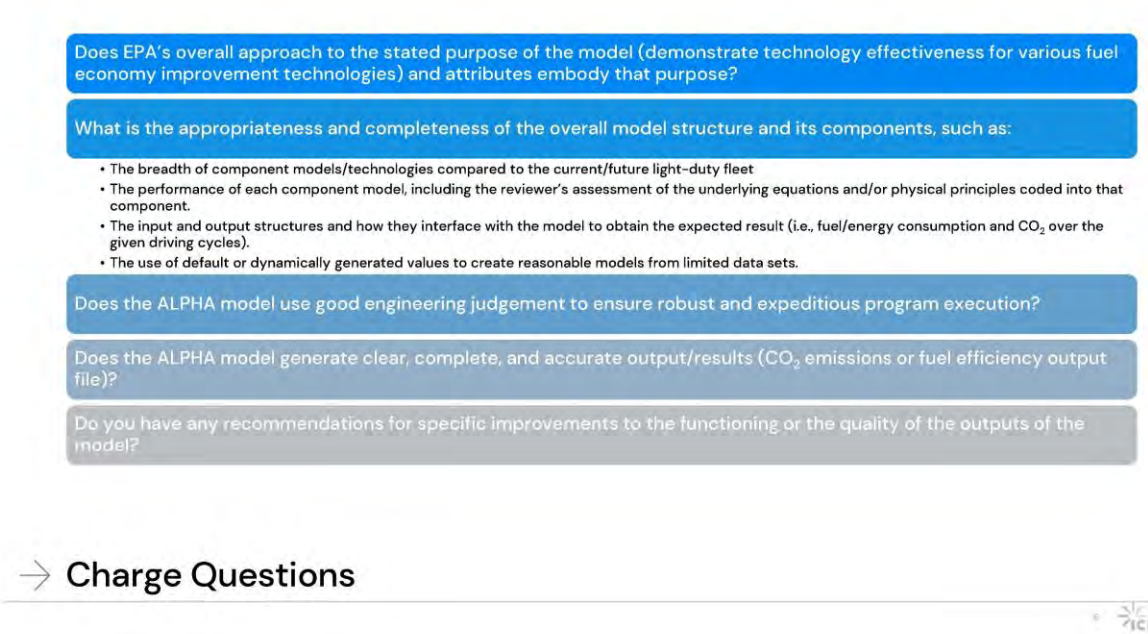
- Oscar Delgado, Ph.D., International Council of Clean Transportation
- Shawn Midlam-Mohler, Ph.D., Professor, Ohio State University
- Sujit Das, Principal Engineer, Strategic Analysis Inc.

Background of the Peer Review

- The Peer Review will evaluate the **accuracy** and **completeness** of the new **ALPHA electric vehicle model**
  - BEV model concepts and methodologies
  - Expert feedback on technical aspects of ALPHA
  - Specific recommendations to improve quality of outputs

Technical Background and Information


Peer Review Overview


Does EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and attributes embody that purpose?
What is the appropriateness and completeness of the overall model structure and its components, such as:
• The breadth of component models/technologies compared to the current/future light-duty fleet
• The performance of each component model, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.
• The input and output structures and how they interface with the model to obtain the expected result (i.e., fuel/energy consumption and CO2 over the given driving cycles).
• The use of default or dynamically generated values to create reasonable models from limited data sets.
Does the ALPHA model use good engineering judgement to ensure robust and expeditious program execution?
Does the ALPHA model generate clear, complete, and accurate output/results (CO2 emissions or fuel efficiency output file)?
Do you have any recommendations for specific improvements to the functioning or the quality of the outputs of the model?
Charge Questions

Materials to Review:

- ALPHA Model Documentation
- Electric Vehicle Simulations within ALPHA Model

Materials to Submit

- A cover letter that states your name and address of your organization
- A completed Conflict of Interest (COI) form
- Your report addressing the charge questions in tabular format

Materials to Review and Submit

1. September 29, 2022: Charge letter and draft distributed to peer reviewers
2. October 6, 2022: Conference call with EPA, ICF, and reviewers
3. October 20, 2022: Comment/review due via email to Sam Pournazeri Sam.Pournazeri@icf.com

Schedule

Appendix E: Peer Reviewer Selection Memo

To: Jeff Cherry, TO COR, U.S. EPA
From: Sam Pournazeri, Project Manager, ICF
Date: July 1, 2022
Re: Task Order 68HERC22F0351 - Peer Reviewer Selection

Under Task Order 68HERC22R0170, ICF is coordinating an independent peer review of the Electrified Vehicle Simulations within EPA's ALPHA Model on behalf of the U.S. Environmental Protection Agency Office of Transportation and Air Quality (EPA OTAQ).

To assemble the panel of three independent peer reviewers, ICF reviewed a pool of subject matter experts both suggested by EPA OTAQ and identified by ICF through independent research. ICF first assessed the experts' availability to perform the peer review within the timeline agreed upon with the EPA Contracting Officer Representatives (COR). After that, ICF reviewed curriculum vitae and other relevant work to select peer reviewers that represent a combined expertise that cover, at a minimum: understanding of vehicle technology packages including battery technology, hybrid and electric powertrains, e-motors, transmission systems (e.g., shift strategy), and vehicle accessories as well as engine fuel consumption map, and vehicle behavior.

While all candidates were highly qualified to act as peer reviewers, ICF sought to select candidates that can bring diverse and complementary perspective to the peer review process. ICF also evaluated actual or apparent conflicts of interest that would preclude an independent review, in accordance with the EPA Peer Review Handbook Sections 3.4.5 and 3.4.6. To the best of ICF's knowledge, no conflicts of interest were found for the proposed peer reviewers in our preliminary research but will finalize the COI evaluation as part of the contracting process. This peer review selection memorandum presents ICF's initial selection of three proposed reviewers.

Upon the selection of the peer reviewers, ICF shared the qualifications and resume for each proposed peer reviewer with EPA to discuss the strengths that each peer reviewer will bring into this project. Upon discussion with TO COR, ICF finalized the list of peer reviewers.

Peer Reviewer Selection Process

ICF first compiled a set of suggested peer reviewers for the report. This list was based on both EPA's initial recommendations and ICF's suggestions for additional potential reviewers. twelve candidates (five selected by EPA and seven identified by ICF) were considered. ICF also prioritized peer reviewers based on the relevance of their background and experience with the topic of the report. Through an initial contact with the selected peer reviewers, ICF assessed each potential reviewer's ability to perform the work during the period of performance and to identify any association they have with the work that would preclude them from being objective. ICF contacted and communicated with all candidates by e-mail.

In our outreach we identified ourselves as independent contract employees and provided initial information on ALPHA model, including the newly added electric vehicle model and the expected time commitment to exercising the model. We asked the potential reviewers to assess their availability for this study and for their hourly rate. We also collected a curriculum vitae for each peer reviewer that expressed availability and interest in participating.

List of Peer Reviewers

Wallace R. Wade
Chief Engineer and Technical Fellow, Powertrain Systems Technology and Processes Center for Automotive Research

Patrick Hammett
Lecturer, College of Engineering, University of Michigan

Sujit Das
Principal Engineer at Strategic Analysis, Inc.

Oscar Delgado
Latin American Lead / Fleets Center Manager for International Council on Clean Transportation

Hussein Basma
Heavy-Duty Vehicles Associate Researcher for International Council on Clean Transportation

Francisco Posada
Project Lead for Engineering Associates, South America

Anup Bandivadekar
Environment Program Officer at William and Flora Hewlett Foundation

Shawn Midlam-Mohler
Professor of Practice and Director of Ohio State University Simulation Innovation and Modeling Center

Aymeric Rosseau
Interim Director of Center for Decarbonization Solutions Deployment for Argonne National Laboratory

Linda M. Miller
Ex. Manufacturing Director, Powertrain Operations, Ford Motor Co.

Dan Meszler
Principal Researcher at MES

John M. German
Senior Fellow for International Council on Clean Transportation

Final List of Peer Reviewers

Upon completion of the initial contact, the top three peer reviewers selected for this project agreed to participate in this peer review process. The rest of the peer reviewer candidates were either not available, not interested (e.g., retired), or had concerns with the limited time allocated for the review (i.e., 20 hours). The resumes for the three selected candidates were collected and shared with U.S. EPA TO COR. Upon approval from U.S. EPA TO COR, ICF initiated the subcontracting process with the selected peer reviewers. Below is the final list of the peer reviewers that will serve on this task order.

The three selected peer reviewers (including the ICCT team) provide a diverse combination of expertise in evaluating the ALPHA model. Sujit Das, with 37 years of experience in energy efficiency research, has served as the peer reviewer of the ALPHA model back in 2016, and has published articles related to powertrain design for advanced fuel vehicle technologies. Shawn Midlam-Mohler is a Professor of Mechanical Engineering at Ohio State University, with expertise in engine selection, modeling, and control development for an extended range electric vehicles as well as vehicle simulations and powertrain optimization. Oscar Delgado and ICCT team also brings in years of experience in modeling advanced technologies and developing tools to support Global commercial fleets in their transition to zero-emission vehicles.

Sujit Das
Principal Engineer at Strategic Analysis, Inc.

Shawn Midlam-Mohler
Professor of Practice and Director of Ohio State University Simulation Innovation and Modeling Center

Oscar Delgado
Latin American Lead / Fleets Center Manager for International Council on Clean Transportation**

*** Note that while Oscar Delgado will be our point-of-contact, ICCT has decided to review the model as a team (Oscar Delgado, John German, Hussein Basma).*