External Peer Review of EPA's OMEGA Model

Final Peer Review Summary Report

United States Environmental Protection Agency

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

Prepared for EPA by
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United States
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1.0 INTRODUCTION

This report documents the results of an independent external peer review of the U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality's (OTAQ), OMEGA version 2.0 model and documentation.

ERG (a contractor to EPA) organized this review and developed this report. The report provides background about the review (Section 2), describes the review process (Section 3), provides a high-level summary of reviewers' comments (Section 4), and includes reviewers comments with EPA's responses (Section 5). Appendix A provides resumes for the selected reviewers, and Appendix B provides the charge to reviewers. Reviewer comments are presented exactly as submitted, without editing or correction of typographical errors (if any).

2.0 BACKGROUND

EPA/OTAQ develops its programs to control CO_2 and other greenhouse gas (GHG) emission measurements in onroad and nonroad vehicles and equipment, there is a continuing need to evaluate the costs and benefits of any such regulations. As such, EPA has developed its Optimization Model for reducing Emissions of Greenhouse Gases from Automobiles, or OMEGA model, to facilitate its analysis of the costs and benefits of the control of GHG emissions from cars and trucks.

The EPA OMEGA model applies various technology packages to a defined set of vehicles to meet a specified GHG emission target and then calculates the costs and benefits of doing so. The GHG target can be a flat standard applicable to all vehicles within a vehicle class (e.g., cars, trucks, or both cars and trucks) or the "target" can be in the form of a curve which varies the target as a function of a defined vehicle "fleet." GHG emission targets are specified in terms of CO_2-equivalent emissions. They can simply be CO_2 emissions from the tailpipe or can be a combination of tailpipe CO_2 and refrigerant emissions.

3.0 PEER REVIEW PROCESS

EPA tasked ERG with identifying four reviewers who had no conflict of interest (COI) in performing the review and who, collectively, met the following selection criteria:

- vehicle operations and analysis, including the physical process of generating and controlling vehicle emissions.
- linkages between mobile source emission modeling and transportation modeling and planning.
- application of current mobile source emissions models for analysis for regulatory purposes and/or policy evaluation.

ERG initiated a search process, asking interested candidates to describe their qualifications and respond to a series of "Conflict of Interest" (COI) analysis questions. ERG carefully screened submissions to identify a pool of qualified, COI-free candidates. From this pool, ERG selected four experts (listed below) who collectively best met the selection criteria. ERG contracted with the reviewers after EPA verified that they were appropriately qualified.

- Sujit Das, MS, MBA; Senior Research Staff Member, Oak Ridge National laboratory
- John M. German, BS; Consultant, JG Automotive Consulting, LLC
- Jeremy J. Michalek, Ph.D.; Professor, Carnegie Mellon University
- Richard A. Rykowski, MCE; Independent Engineering Contractor, Environmental Defense Fund

ERG provided reviewers with access to a secure ERG FTP site to download all review materials and the technical charge to reviewers (Appendix B). Prior to the start of the review, ERG organized and facilitated a virtual meeting between reviewers and EPA to provide reviewers an opportunity to clarify their responsibilities for the review. EPA provided background about the review materials and responded to reviewers' clarifying questions. Reviewers then worked individually (i.e., without contact with other reviewers or EPA) to prepare written comments. During this time, three reviewers sent a request for technical clarifications and additional materials to ERG. ERG forwarded this request to EPA and provided EPA's responses to all four reviewers. Reviewers completed their individual reviews and submitted their written comments to ERG. ERG provided the individual reviewer comments to EPA. EPA then responded to reviewers' comments and provided a response to comments document to ERG. ERG then prepared this report, including the high-level summary of reviewers' comments (Section 4.0).

4.0 SUMMARY OF REVIEWER COMMENTS

This section provides a high-level summary of the comments submitted by the four peer reviewers (Mr. Sujit Das, Mr. John German, Dr. Jeremy J. Michalek, and Mr. Richard Rykowski) on the OMEGA version 2.0 model to analyze the effects of new GHG standards and policies for light-duty vehicles. EPA's charge to the reviewers requested their expert opinions on the concepts and methodologies upon which the model relies and whether the model correctly executes the associated algorithms. EPA's charge also asked them to comment on specific aspects of the model's design, execution, outputs, and documentation.

High-Level Themes

All reviewers commented favorably that they appreciated the increased capability and complexity of OMEGA2 over the previous OMEGA version. In general, the reviewers provided numerous specific detailed, complex, and nuanced comments and recommendations that indicated a good understanding of the model's design. The most common category of comments consisted of recommendations for improving the model's documentation by adding further explanations or specifics to enhance the user's understanding.

The second most common category of reviewer comments concerned the model's overall approach, including the functions of each module. Reviewers commented on specific details, recommended improvements, and noted unexpected results where observed. In several cases, reviewers noted specific unexpected results and recommended that EPA should either repair the model's respective function or improve the documentation to explain that the function in question intentionally produces the unexpected result. The vast majority of reviewer recommendations for new or additional functionality focused on specific enhancements of the existing modules; reviewers did not recommend additions that deviated significantly from the current model's scope. EPA will likely be able to address almost all recommendations using currently available information and knowledge.

Most Common Specific Recommendations and Comments

Certain topics were raised by multiple reviewers. For example, all reviewers commented on some aspect of the model's handling of greenhouse gas (GHG) credits, especially as it relates to manufacturers banking these credits from one year to the next and, in some cases, how credit banking would interact with manufacturers' multi-year model development cycle. Reviewers also indicated that the model did not seem to address the level of technology penetration in the baseline vehicle fleet. They perceived that the model treats the baseline technology penetration as zero and suggested that the true level of baseline technology penetration should be greater than zero.

The interaction between technology, fuel price, and vehicle miles traveled (VMT) also received frequent comment. Reviewers indicated that it was likely that wide-scale implementation of the technologies available in OMEGA2 could cause a significant change to overall fuel prices that should be considered. Also, they indicated the model would benefit from further consideration of VMT rebound due to increased vehicle fuel economy. Reviewers also tended to disagree with the model's assumption that vehicle fuel economy and cost only affect a manufacturer's market share of a particular segment; rather, they thought it likely that overall vehicle sales rates can also be affected by the balance of vehicle cost and fuel economy.

Two details received notable attention from reviewers. First, reviewers expressed general confusion around the hauling/non-hauling segments and how they related to vehicles being categorized as cars versus trucks. This included unexpected GHG emission effects in the outputs of hauling and non-hauling vehicles. Second, reviewers questioned the model converting a car to a truck by the addition of all-wheel drive (AWD) when there was no other technology that, when added, shifted the vehicle to another segment.

Finally, all reviewers commented on some aspect of the model algorithm's treatment of iterative convergence on a final result. Mr. German requested that the convergence criteria and justification be provided in the documentation. Mr. Rykowski thought the documentation would benefit from explanations and warnings to the user indicating the types of inputs that could cause lack of convergence. Dr. Michalek and Mr. Rykowski were concerned about the model's actions when iteration does not converge, as well as the specific algorithms' potential for convergence on suboptimal solutions.

In addition to the key themes and most common comments summarized here, reviewers provided numerous other specific observations and recommendations for the OMEGA model in response to the technical charge to reviewers (Appendix B).

5.0 NARRATIVE COMMENT AND EPA RESPONSES

This section includes reviewers' comments as received by ERG along with EPA's responses to their comments.

> **General EPA Response on Model Revisions:** Note that OMEGA Model version 2.1.0 is the latest version of the OMEGA model that includes both the changes to the model as the result of this peer review and the continued development of the model as the result of the rulemaking process. References below to "current version" and "latest version" are referring to version 2.1.0. References below to "a future version of the model" indicate revisions beyond 2.1.0.

5.1 Comments Submitted by Mr. Sujit Das

5.1.1 General Comments

A significantly enhanced EPA OMEGA 2.0 version model than the earlier OMEGA 1.0 version is an excellent and unique producer-consumer vehicle choice model by minimizing the resulting effects of societal costs and emissions subject to user-input emission policies. It is intended to find a solution which simultaneously satisfies producer, consumer, and policy requirements while minimizing the producer generalized costs. A draft model documentation 300+ pages including the development model version accessible also directly from Github provides the necessary detailed model scope description and its modeling approach capabilities. A well-qualified team with economics background has been involved towards the second generation of OMEGA2 model as evidenced by the model documentation and thorough explanations/responses provided to a wide range of reviewer set of questions. The interactive decision-making process between producer and consumer modules to meet the final annual emission targets (Policy module) is quite complex based on economic theory but reasonable and adequate, could potentially be limited to only experienced economist model users. The logical decision-making process in OMEGA2 seems too complex for the necessary level of review (consisting of a review of at least 90+ pages out of total 300+ pages containing some source code of the model documentation besides the model running) due to the limited effort available to reviewers. Some additional documentation would be useful in terms of logical explanation of various iterative producer-consumer vehicle choice process (suited to a general non-economist audience) before the public model release.

5.1.2 Specific Comments

A summary section in the model documentation would be useful to identify the strengths and limitations of the estimation approach and by specific decision modules in the modeling framework. In addition, how OMEGA 2.0 model distinguishes among other similar publicly available models, if available.

EPA's Response (SD01): Thank you for the suggestion. We will consider adding a background section to the model documentation that provides a broader discussion about the model, and its potential limitations.

The policy-oriented model seems too complex for a novice user. A professional economics background is necessary for interpretation of model results and so it'd be useful if the model documentation could be made more simpler for the general users.

EPA's Response (SD02): We do not agree that a professional economics background is needed to interpret the model results. While some of the internal concepts are based on economic principles, the model outputs are expressed in simple and broadly understandable terms. With that said, we will continue to look for ways to make the documentation clearer and more useful for a broad range of readers and users.

What's the basis of an array of test values for producer "cross subsidy" price multipliers as shown in Figure 4.16? A schematic process flow diagram would facilitate in a better understanding of these multipliers towards the final vehicle sales share outcomes/results.

EPA's Response (SD03): Thank you for the suggestion. Figure 4.2 does show the feedback between the producer and consumer modules in the model's iteration process. We will consider adding some overall schematic to describe the iteration process in a future version of the documentation.

Would be helpful for the novice EPA model users to include a short section on the other EPA complementary ALPHA model with differences between it and OMEGA2 model.

EPA's Response (SD04): As described in the documentation, ALPHA is an optional physics-based simulation tool used to generate vehicle inputs for OMEGA. Alternatively, OMEGA users may use any other approach (e.g., other simulation tools, or empirical data) to generate the inputs required by OMEGA.

It'd be good to have a model calibration/validation, if not already done so.

EPA's Response (SD05): There are test inputs that can be used to ensure that the model runs, and the users Python environment contains the necessary libraries. Additionally, the user can make use of EPA's model runs and compare local results to EPA's results to ensure that the model generates equal values. Calibration/validation of inputs unique to the user's analysis are the responsibility of the user.

It'd be helpful to update the model user documentation by taking into consideration many excellent detailed insights/responses to reviewers' comments.

> **EPA's Response (SD06):** We intend to do this as appropriate.

It'd be helpful to include explicitly the learning effect on decreasing BEV production cost with an increasing vehicle production volume in its generalized cost equation representation.

> **EPA's Response (SD07):** This has been implemented in the current version of the model with a cost reduction curve based on cumulative GWh of batteries produced.

It'd be good to consider in future updates (as suggested in one of the EPA's responses) to evaluate how the algorithm might explore strategies where producers are intentionally over/under target in the various years so that they minimize producer generalized costs over the entire analysis period, as opposed to the current version's use of a 0 Mg CO2 credit target (+/- a tolerance) in each year.

> **EPA's Response (SD08):** Thank you for the suggestion. The current version does account for the use of historical credit banks, and the carry forward and carry back of credits to offset over target years. However, we have not implemented the strategic overcompliance and carry forward of credits in order to reduce total costs over multiple years. Please see our response to reviewer comment RR05.

Steps for running the model seem not very straight forward to a novice user using the existing model GUI. It was hard to locate some of the listed files in the model documentation. Additional step-by-step flow diagrams including the file listing with a clear indication of necessary user inputs for both necessary pre-processing and post-processing would be useful to be included in User's manual. In addition, a definition glossary of major variables including a data dictionary would be useful.

> **EPA's Response (SD09):** The GUI was designed to provide users the ability to run model examples and become familiar with the various input and output files along with the directory structure. Many updates have been implemented in the documentation describing these details.

It was quite interesting to note that the consumer preference dominates the final production decision in case the convergence doesn't occur between producer and consumer preferences.

> **EPA's Response (SD10):** The current version of OMEGA accepts the consumer shares one market class at a time, which gives the producer more opportunities to adjust their production decisions. In general, it's the case that the consumer and producer have different preferences and there is some negotiation between them in the form of the cross-subsidy iteration. The larger the cross-subsidy range, the more likely the producer is to achieve their desired shares.

EPA should pursue its suggestion to ensure that its complementary ALPHA results reliably represent absolute emissions levels (consistent with OMEGA 2.0) as a function of vehicle loads, performance capabilities, and technology applications.

> **EPA's Response (SD11):** Independently of the OMEGA model development, we have a team of people that are completing this work, comparing ALPHA results with test data from certification. A revised, final set of ALPHA runs will be completed soon.

Does the past decision made affect its future decision? If so, has the recursive decision-making approach been used?

> **EPA's Response (SD12):** Yes, in the current version of OMEGA, prior production decisions affect the current year's production decision. For example, redesign intervals determine the technology on the vehicles that aren't available for redesign. There is also now a rate limit that restricts the maximum rate of change of shares. For example, the limit would restrict a wholesale changeover from ICE to BEV over a user-definable time span. As a result, the available share range in the current year is partially a function of the prior year and the ramp rate. We are also investigating other year-over-year production decision limitations and effects. The decision-making process is not recursive at this time.

Is there any consideration of efficiency improvement of conventional ICEs and cost similar to EVs?

> **EPA's Response (SD13):** The efficiency of technologies considered are defined by the user in the input files. The input files for emissions rates and energy rates are tied to model year, so the user can specify those values improving over time. The user can apply time-based learning curves to adjust costs over time.

5.2 Comments Submitted by Mr. John M. German

5.2.1 General Comments

Overall approach, specific approaches for modeling individual modules, and methodologies chosen

I want to acknowledge the level of improvements to OMEGA 2 from OMEGA 1. The original OMEGA model (I was one of the original reviewers) was rather crude, requiring massive amounts of work to both the inputs to the model and in processing and interpreting the results. OMEGA 2 is not just updated, it is essentially a new model that can handle feedback loops and interactions between different modules and inputs, as well as adding internal checks, more inputs, more flexibility in inputs, and a wide range of stock "auto-generated image" output files.

Note that I did not do a general review of Sections 6 (Developer Guide) or 7 (Code Details) of the documentation, as these are beyond my expertise.

Also note that because I started reviewing OMEGA 2.0.0 documentation before I received 2.0.1 documentation (and because 2.0.1 did not include page numbers), all documentation references below are to 2.0.0.

The six model updates (i.e. expanded model boundaries, independent policy module, modeling of multi-year strategic producer decisions, addition of a consumer response component, addition of feedback loops for producer decisions, and use of absolute vehicle costs and emission rates) are all welcome additions.

The four modules, Producer, Consumer, Policy, and Effects appear to be structured well to allow changes in one module to interact with the other modules while minimizing code changes throughout the model.

Flexibility in vehicle resolution (page 34) and market class resolution (page 35), as well as measures to address consumer heterogeneity (page 36), are also welcome.

Calibrating to projected elements (page 41) is essential – glad to see this.

Sample input files, appropriateness, and completeness

The input files appear to cover a wide range of the potential influences on emission compliance and the impacts of the standards.

Conceptual algorithms and equations: accuracy and appropriateness for technology application, market inputs, and compliance calculations

Based on reviewing the documentation, the conceptual algorithms and equations appear to be accurate, although this was not a primary focus of my comments.

Documentation: clarity, completeness, and accuracy

Description of how to run OMEGA, Sections 3.1 to 3.2, is good. Description of output files in Section 3.3 is also good, although it could be slightly improved.

Section 4 description is a good overview and is mostly clear without being too long. Fig. 4.2 showing OMEGA process flow is very helpful.

Policy Module (Section 4.2), Consumer Model (Section 4.4), and Physical Effects Calculations (Section 4.6) descriptions very clear.

Congruence between conceptual methodologies and program execution

The complexity of the simulated_vehicles.csv file, especially the multiple rows for seemingly identical vehicles (see comments in Section 4 and 7), precluded me from making any changes to the technology input files (technology being my primary focus) and examining changes to the results.

Visualization output: clarity, completeness, and accuracy of technology display

The variety of stock "auto-generated image" output files "intended to provide a high-level view of the key results" is impressive. Variety and depth of .csv output files is also impressive.

Note that I also included comments on the .csv output files in this section.

Recommendations for functionalities beyond "future work"

Given the relatively small number of references to "future work" in the documentation, I simply placed my recommendations for future new functionalities in my comments on the previous sections.

5.2.2 Specific Comments

4.3 and 2nd set of EPA responses to peer reviewer questions pages 7-8

Producer Module, re discussion in the 2nd set of EPA responses to peer reviewer questions on pages 7-8 on converting a car to a light truck (likely by adding AWD/4WD to a 2WD CUV). The primary advantage for a producer to make this switch is to gain a less stringent emission standard. Perhaps I misunderstood EPA's response, but it did not seem to directly address the technology cost savings from certifying to a less stringent CO_2 standard. Bottom line is that OMEGA should **model the producer decision as the sum of the technology cost savings from certifying to a less stringent CO_2 standard plus the (heterogeneity) consumer value of AWD/4WD minus the incremental cost of adding AWD/4WD.** If OMEGA does not already perform the calculation this way, it should be revised.

EPA Response (JG01): EPA agrees that manufactures may consider changing vehicle attributes as part of a compliance plan under an attribute-based standard. Under the current light-duty GHG standards, footprint, ground clearance, AWD, and an open cargo bed are some of the key consumer-facing attributes that determine the GHG targets and might therefore be included as potential vehicle changes in response to a new GHG policy. We have updated the model to include a user-definable consumer valuation of footprint as part of the producer generalized cost value used in the cost-minimization function for producer decisions. We will consider incorporating other attributes with explicit consumer valuation parameters in a future version of the model. However, the model does not currently accommodate shifting of reg classes by changing vehicle attributes as a producer decision.

4.3, 4.4, especially pages 48-49

The sidebar on pages 48-49 states that "OMEGA allows the user to define the consumer decisions from the producer's perspective, which may be different from (or the same as) the representation within the Consumer Module." Allowing the OMEGA user to define separate consumer decisions from the producer's and consumer's perspective is nonsense. This implicitly assumes that the user knows better than producers what the consumer response will be. Given the manufacturers' very existence is predicated on the best possible understanding of their consumers and the vast amount of confidential data available to producers but not the public, OMEGA should not allow the user to second-guess the producer's perspective. **The Producer and Consumer Modules should use the same definitions of consumer decisions.**

- Note that this is not inconsistent with allowing the user to set parameters that affect the Consumer Module output, only that the same parameters must be used for the Producer Module.

EPA's Response (JG02): We are currently using the GCAM model's equation forms for determining the ICE-BEV consumer demand share. In those equations, consumer generalized cost is represented as a cost per mile value. The user can select input parameter values for the producer generalized cost equation, expressed in dollars, that are consistent with the cost per mile values for consumer generalized cost. Although we did not adopt the reviewer's recommendation to use the exact same formulation for consumer demand in the producer and consumer generalized cost for this version of the model, we will continue to consider that change in a future version of the model.

4.3.3, Table 4.5, page 50

"epa_size_class" is defined as "Standard" SUV and pickups, while Fig. 4.3 on page page 42 uses "small" and "large" definitions of size class. Need to be consistent.

EPA's Response (JG03): This various vehicle classifications used in the model can be defined by the user in the model input files. We will consider revising the model documentation in a future release to clean up any inconsistencies in class names used in the examples.

4.4 - A concern with the Consumer Module is that it can change the proportion of sales attributes to different market classes. This affects compliance with the standards. Are you assuming that OEMs will make these same sales adjustments when they plan on how much technology they need to comply with their targets? If yes, need to clearly state this in the documentation. If not, then this portion of the Consumer Model will cause OEMs to under or over comply.

- Note that the other parts of the Consumer Model are not affected by this concern (e.g. new vehicle sales if sales attributed to different market classes are not affected, total vehicle stock, and total vehicle use.)

EPA's Response (JG04): We agree that it is important that the model maintain consistency between the GHG targets for a given policy definition and the vehicle attributes of the produced vehicles. In the model's producer compliance search, each candidate solution is represented by its producer generalized cost and compliance credits. The compliance credits are calculated relative to a candidate solution's specific GHG targets, which will depend on the vehicle attributes in that solution. Similarly, the GHG certification values are specific to the vehicles in that solution, which ensures that each solution maintains consistency between GHG targets, GHG certification values, and therefore GHG credits.

There appears to be no way to **compare incremental technology penetration, cost, and GHG reduction versus the baseline vehicles** in OMEGA 2, as the baseline vehicle input file (vehicle.csv) does not contain information on technology penetration in the baseline fleet. This functionality should be added. Or, if it does already exist, the documentation needs to explain how it is done.

EPA's Response (JG05): The model operates based on absolute GHG emissions and cost, rather than the incremental effectiveness and costs. The model outputs are also reported as absolute values, from which the user can determine the incremental effects of any sessions. Conversely, if we only provided incremental values, it would not be possible to determine absolute values.

<u>4.1.1, page 36</u>

For 'Producer Resolution', the only options are perfect trading or no trading. Neither of these options are realistic. **Future versions of the model should include an option for individual entities with imperfect trading between entities**.

EPA's Response (JG06): Thank you for the comment. We have incorporated a 'credit market efficiency' parameter that can be set by the user. A value of '1' represents a perfect credit market; a value of '0' represents no credit trading provisions. Values between 0 and 1 represent imperfect trading, where manufacturers with cost-minimizing compliance pathways that involve the purchase of credits will apply more technology than they would under perfect trading. And as a result, some of the industries credits will expire, unused.

<u>4.1.4 page 41</u>

Among the "purely exogenous" items listed is "the state of available technology". I understand this is how virtually every technology analysis has always been done (with the notable exception of the 2013 NAS study on Transitions to Alternative Vehicles and Fuels). However, new technology beyond the "state of available technology" has continuous been developed. There is every reason to believe that this will continue to occur in the future (e.g. 2021 Roush technology reports). **It is important for projections out to 2050 to include some way to account for future technology, beyond that just contained in currently "available."**

EPA's Response (JG07): The user can supply the model inputs so that represents their own definition of "available technology", including potential technologies that might be available in the future. We will consider revising the model documentation to clarify that "available technology" does not need to be limited to technologies that are in current mass production.

<u>4.1.4 page 42</u>

Size class descriptions. Fig. 4.3 shows that the default size classes divide pickup truck, van, utility, and crossover classes into only two sizes each (small and large), compared with 6 different sizes for cars. Given the shift to pickups, utility, and crossover vehicles, especially the growth in mid-size LDTs, it is time for **EPA to develop default size classes for at least small, midsize, and large crossover, utility, and pickup vehicles**.

EPA's Response (JG08): The reviewer is referring specifically to the context size class definition that is used for projecting fleet mix in future years. The demo example uses AEO projections, and therefore maintains the AEO size class definitions and names. If a user has an alternate data source with greater resolution for projecting changes fleet mix for types of vehicles, they can specify those class names and associated projected volumes for the analysis context session in the new_vehcile_market.csv input file.

4.2 page 46 and .cvs input files

One of the inputs to the Policy Module is "offcycle_credits". This gives g/mi credits for listed off-cycle technologies, which are turned off and on in simulated_vehicles.csv.

- The Off-cycle credits are given in fixed gCO2/mi. However, off-cycle technology related to efficiency (e.g. AC efficiency) are not fixed, but are proportional to the vehicle gCO2/mi emissions. **This should be fixed in future versions of OMEGA, to avoid giving excess off-cycle credits as vehicle efficiency improves**.

EPA's Response (JG09a): Thank you for the suggestion. The model has been revised to allow the user to specify AC efficiency and off-cycle credits based on any discrete vehicle attribute. For example, fueling class, reg class, or a combination of the two in a combined attribute. For future revisions, we will consider this suggestion for make the credit values a function of a continuous vehicle attribute, such as efficiency.

- The SAFE rule and EPA's and NHTSA's revision of the standards through 2026 treat off-cycle and on-cycle technologies separately, with off-cycle technologies being applied first regardless of their cost-effectiveness. However, manufacturers freely choose between on-cycle and off-cycle technologies and select the most cost-effective ones when planning for compliance. **OMEGA needs to do the same and compare cost-effectiveness of all technologies, including both on-cycle and off-cycle CO2 reductions, simultaneously**. As the off-cycle credits are turned off and on in the same file as the on-cycle credits, it appears that OMEGA 2 might finally be doing this.
    - **If OMEGA 2 is treating on and off cycle technologies the same, this is important and should be stated as one of the updates to the OMEGA model in section 1.**
    - **If OMEGA still has some differences in how it implements on and off cycle technologies, this should be fixed in future versions.**

EPA's Response (JG09b): Thank you for the suggestion. The model does treat off-cycle technologies in the same way was other technologies. Specifically, the model applies off-cycle technologies when they are cost effective, and not automatically as was the case with off-cycle credits in modeling used by EPA previously. We will consider providing a specific description of this approach in a future version of the model documentation.

4.4.3 page 66

While it is a good first step to address heterogeneity, the method implemented in OMEGA appears to be simplistic and require the user to define every item. For example, page 46 states:

> "If users identify heterogenous consumer groups with separate sales share responses, the analysis context must include the appropriate inputs. For example, the proportion of the vehicle buying population in urban and rural areas for each year being analyzed within the model." This is confirmed by the inputs in sales_share_Params-contxt_a.csv.

Future versions of OMEGA could consider separately modeling different types of customers (e.g. early adopters, mainstream, late majority) as has been done by David Greene. This could both improve accuracy and reduce the burden on the user to define the inputs.

> **EPA's Response (JG10):** The default ICE-BEV share consumer demand model is based on the Pacific Northwest National Laboratory's GCAM model. The share weight parameter is specified as a function of calendar year, in the form of a logistic ('S' shaped) curve, which is a common way to represent the progression over time in the acceptance of a new technology in a heterogeneous consumer market. Although the GCAM model represents the market heterogeneity using a continuous logistic function, if a user has identified an alternative consumer choice model with discrete consumer segments, it would be possible to implement it into OMEGA with a new consumer module. We will continue to consider whether any other consumer choice models may be appropriate substitutes for the GCAM model, and possibly include in a future version of the model.

4.4.4 pages 69-71

Vehicle stock. Vehicle life has continuously increased for decades. Thus, it would be appropriate to **at least include an option to increase the reregistration rate as time goes by**, if not make it the default for OMEGA.

> **EPA's Response (JG11):** We agree that this is useful functionality. We have added a 'start_year' parameter to the reregistration rate input file. The user can now specify unique reregistration rates by calendar and model year.

4.4.4 p 71

States, "The demo analysis does not currently implement VMT rebound estimations." I assume that the official release of OMEGA 2 will include VMT rebound estimations?

> **EPA's Response (JG12):** We have implemented VMT rebound in the OMEGA effects module. The user can specify VMT rebound values for BEV and ICE fueling classes separately.

4.3.2. page 49 & 1st set of questions from OMEGA Peer Reviewers page 13

Documentation states (page 49), "At this time, OMEGA assumes that producers aim to meet the GHG target in each year, with any banked credits used only to make up differences between the certification and target values."

The EPA Response states, "For future updates, we are evaluating how the algorithm might explore strategies where producers are intentionally over/under target in the various years so that they minimize producer generalized costs over the entire analysis period, as opposed to the current version's use of a 0 Mg CO_2 credit target (+/- a tolerance) in each year." And asked for reviewer responses.

It is extremely important to allow manufacturers to use up banked credits by intentionally exceeding CO_2/mi target levels in various years; by modelling credit carry-forward strategies. This can be seen in the industry's deliberate undercompliance in every model year from 2016 to 2020, when the industry's CO_2/mi emissions exceeded the performance requirements each year (EPA 2021 FE Trends report). As explained in an ICCT blog (https://theicct.org/blog/staff/us-fuel-economy-trend-reflects-business-strategy-not-tech-challenge) this is just good planning on the part of manufacturers, as using banked credits reduces the overall cost of compliance. This strategy must be included in EPA's modeling.

It is less clear to me the value of allowing manufacturers to intentionally over/under comply in various years and to model credit carry-forward and carry-back strategies. This would be needed if EPA were modeling 5-

year design cycles, but in the absence of design cycles the additional complexity of modeling a general over/under compliance strategy may not be worth the effort.

EPA Response (JG13): In the current version, the default behavior is to allow overcompliance only when a producer needs to make up for a year that was over target, or the consumer demands more emissions reductions than are required by the policy. We have implemented logic for the producer's compliance strategy that allows under-target performance when it minimizes producer generalized costs for that model year. This feature is still under development and can be enabled or disabled using the 'voluntary_overcomliance' setting. Similarly, we have revised the logic so that the producer will use historical banked credits before they expire, even if it results in being over target for the early analysis years. We have not implemented the change that allows the manufacturer to either strategically generate credits based on a prediction of preferring to use those credits in later years, or strategically run a deficit based on a prediction that credits can be more cost effectively generated in later years. We will continue to consider whether it is possible in a future version of the model to evaluate various under- and over-target pathways as part of a compliance trajectory that minimizes costs over all analysis years in total, rather than for each analysis year separately as is the current logic.

4.4.1 page 58

Documentation states, "When a (typo?) modifies a submodule, they must ensure that the submodule retains consistency with the other submodules within the Consumer Module, as well as with the rest of OMEGA. For example, if the market class submodule is changed from the demo analysis version, the sales share submodule must be updated as well since sales shares are determined by market class."

In future versions of OMEGA, **might investigate if the model can make appropriate adjustments to the other submodules** when the user modifies a submodule.

EPA Response (JG14): Thank you for the suggestion. We will continue to consider how to make any future versions of the model more adaptable and user friendly.

.CSV Files - It would be helpful, at least for the more complicated files, to include a sheet with a brief description of the variables in the file.

EPA Response (JG15): Thank you for the suggestion. We plan to update the description of variables in the documentation in a future release. We note that adding descriptions directly to the csv files would introduce the potential for errors in the formatting and data reading. Furthermore, some files have variable names repeated in multiple rows and/or columns and could not be easily tagged with field definitions.

Simulated vehicles.csv

It appears that FTP results are reported by bag (T:W and Z:AC), but without reporting overall CO2 or kWh/mi. Does OMEGA do this calculation?

- It might be helpful if the documentation said that FTP inputs have to be reported for each bag (and that OMEGA calculates overall FTP results?).

EPA Response (JG16): We have implemented the capability for the user to define drive cycles using any combination of weighting. For example, the FTP drive cycle can be specified by individual bags, or as a single weighted cycle. We will consider updating the documentation to clarify this flexibility in a future release.

There are multiple rows for each combination of year, cost curve class, technology, and curb weight. For example, rows 27477-27487 are all 2026 LPW_LRL HEVs with AC leakage, AC efficiency, GFI, and 2981 curb weight. Yet each of the 11 rows has a different new vehicle cost and FTP emissions.

- The multiple rows appear to be linked to an undefined 'vehicle_id'. However, I was not able to find any definition of the vehicle attributes associated with this vehicle ID, either in the documentation or in the input files. **Documentation should explain how vehicle IDs are generated** and there needs to be an **input file added with the attributes associated with each vehicle ID** (e.g. technology, vehicle class).
- I checked Section **7.2.1.3.2** on the cost_cloud module in Python but it was not clear to me what the "cost cloud frontiers" discussed in this section referred to.

EPA's Response (JG17): The vehicle IDs are automatically generated in sequence within the model, with no meaning apart from the function of uniquely identifying individual vehicles both within and across years. We will consider adding this clarification to in a future version of the model documentation.

The technology choices appear to be quite limited, with just HEV, PHEV, BEV, weight reduction, 2 types of DEAC, CEGR, atk2, GDI, and 2 types of turbos (turb11 and turb12), plus 4 types of off-cycle credits (AC leakage and efficiency, high efficiency alternator, stop/start). This is quite limiting, especially beyond 2025 when technologies such as e-boost, variable geometry turbos, and lower bore to stroke ratios should become common.

- Is this just because the "demo" files are not intended to be complete? If so, should state clearly when discussing the demo examples in Section 3 that the technology files are just examples and are not complete.
- **Is it possible for users to add technologies to the simulated vehicles .csv file, for example by adding new columns?** If so, should state this someplace in the documentation and give some idea how to do this.
- I also checked Section 7.2.1.3.2 on the cost_cloud moduel in Python, but this does not even mention technology options, much less how to add them.

EPA's Response (JG18): We provided the demo for the peer review for the purpose of illustrating the key model functions using a simplified set of inputs. The user can add any number of possible technologies to the simulated_vehicles.csv input files, as long any unique technology flags are represented in the powertrain_costs.py module, and the associated costs defined in the powertrain_costs.csv input file.

<u>vehicles.csv</u>

This file of baseline (currently 2019) vehicles **does not include a list of technologies already implemented in the baseline fleet**. How can you calculate incremental costs and CO2 reduction without knowing the baseline vehicle technologies?

Also, costs in the baseline 'vehicles.csv' file are **MSRP**, while costs for future vehicles in 'simulated vehicles.csv' are **manufacturing costs**. How does OMEGA calculate incremental costs? Should at least be explained in the documentation somewhere.

EPA's Response (JG19): The vehicles.csv base year input file now contains fields for 'cost_curve_class' and 'body_structure_material' that describe the technology packages in the base year fleet. This change was made to accommodate the implementation redesign cycle constraints in the model, and the requirement that the powertrain package and body structure be carried over from one year to the next until the next redesign opportunity. This includes the years following the base year, and the constraint that base year technologies be carried over for as long as a full design cycle span depending on when the prior redesign year was.

<u>4.4.4 p 71</u>

Reiterate that the official release of OMEGA 2 should include **VMT rebound estimations.**

It appears to be virtually impossible to modify the technology input file due to it's complexity, for example to evaluate the impact of changing the cost or effectiveness of a single technology. It would be helpful to implement a way to do this in future versions of OMEGA.

Or, as an alternative, the OMEGA documentation could discuss how to link OMEGA to ALPHA and provide some guidance on how to modify technology inputs to ALPHA in order to generate new OMEGA input files.

> **EPA's Response (JG20):** We provided the demo for the peer review for the purpose of illustrating the key model functions using a simplified set of inputs. The user can add any number of possible technologies to the simulated_vehicles.csv input files, as long any unique technology flags are represented in the powertrain_costs.py module, and the associated costs defined in the powertrain_costs.csv input file.

<u>1.1 page 2; 4.1.1 page 33</u>

Fig. 1.1 diagrams how technology is input into OMEGA 1, but does not for OMEGA 2. Would be helpful to diagram here (and in Fig 4.1) and discuss in Section 1.2 **how the ALPHA model fits in with the OMEGA model.**

> **EPA's Response (JG21):** This is outside of the scope of the OMEGA model and documentation. The user can define the technology energy consumption rates and CO2 emissions rates in the simulated_vehicles.csv input files using whatever data sources are deemed appropriate. Our use of ALPHA vehicle simulations, or any other simulation tool would be described separately in future rulemaking documentation.

<u>1.2 page 4</u>

Again, as EPA uses the ALPHA model to generate technology inputs, an overview of how ALPHA fits with OMEGA would be helpful in Section 1.2

<u>2.3 page 8</u>

No mention of the executable file for Mac computers, only win.exe

<u>3.1 page 10</u>

Might help to provide some examples of Input Batch Files for Element 2 – is there just one OMEGA input file? If there are more than one, what might they be?

- I note that Section 3.3. on output files contains a great deal of discussion of the various output files, but there is nothing for input files.
- I also see that Section 4.3.3 Table 4.5 contains a definition of the input files. If you don't add a section on input files here, similar to Section 3.3 for output files, Section 3.1 should at least reference Tables 4.2, 4.3, 4.4 and 4.5.

<u>3.2.1 & 3.2.2 page 11-12</u>

A new term, 'Configuration file' is introduced. Should explain what is contained in the Configuration file (e.g. I don't understand how this differs from the Input Batch File).

<u>3.3 page 16</u>

Where is the “out” folder located?

There is no description of the “Results” tab in the documentation.

<u>3.3.1 page 17</u>

- Again, should state where the results files can be found.
- Demo example is “reading the manufacturer compliance plot”, but this is not one of the files described in Table 3.1
- There are three output .png files that are not listed in Table 3.1 on page 17: Sales v Year and V Cost Mkt Cat/Cls.

<u>3.3.1 page 18</u>

Figure 3.7:

- Might be helpful to output a description with the .png for Figure 3.7, as I found it difficult to follow Figure 3.7 even with the description.
- What is calendar year used for? (didn’t see this in description)

<u>3.3.1 page 19</u>

What does “hauling” and “non-hauling” mean?

Why does “hauling” have more stringent CO2 targets than “non-hauling” in upper panels (the reverse of the lower panels)?

<u>3.3.1 page 24</u>

Caption for Fig. 3.11 should state these are changes in stock parameters and that the results do not include rebound effects.

<u>3.3.1 page 24-25</u>

For costs, BEV cost parity is reached far later than most analyses. **Would help to describe what the vehicle mix assumption is.** BEV costs are much more strongly affected by the mix of cars, CUVs, SUVs, and pickups than ICEs, so assuming a small car share (for example) would delay cost parity.

<u>3.3.2 page 26</u>

Again, should state where the output files can be found.

<u>3.3.2 page 27</u>

The ‘physical_effects.csv’ output file has about 50,000 rows. It might help to give the user some idea how to handle these rows. For example:

- To generate Figure 3.16, were the total GHG emissions in each row simply totaled by year and BEV-upstream, ICE-tailpipe, and ICE-upstream?
- Should also discuss how to conduct more detailed analyses, which appear to depend on how to interpret ‘vehicle_ID’ (and ‘reg_class_id’?), as there are multiple rows with no other distinction. Is there a file somewhere that defines what they mean and the attributes of each index? (I did a search for vehicle_id, but came up with nothing helpful.) **Should state where to find the definition for each vehicle_ID and reg_class-id.**

Note that if they are not defined anywhere, it makes it impossible to do more detailed analyses of the results.

Note that this also applies to many other files, such as the technology tracking output file and Figure 3.17.

<u>3.3.2 page 31</u>

Figure 3.18 has a "fuel_pretax_cost", but there is no electricity cost. Electricity is not normally defined as a "fuel", so if this parameter includes both, should change the name.

- On page 80, '$\text{FuelConsumption}_{\text{kWh}}$' is used for Electricity consumption, confirming the problem in Figure 3.18. Should use 'energy' cost and consumption instead of 'fuel'.

Also, what is "refueling_cost" and why is it different from fuel cost?

<u>4.1.3, p 39</u>

Some of the elements in Table 4.2 have values instead of 'input file names', i.e. New Vehicle Price Elasticity of Demand and Max and Min Producer Cross Subsidy Multiplier. The last sentence on page 38 before Table 4.2 says, "Table 4.2 shows the complete set of input files and settings for Context A as defined in the 'demo_batch-context_a.csv' file." However, it would be helpful to:

- Start by briefly discussing the role of the batch-context files in defining the input files that OMEGA looks for.
- More clearly state that the New Vehicle Price Elasticity of Demand and Max and Min Producer Cross Subsidy Multipliers can be found and changed in the batch-context input file (e.g. demo_batch-context_a.csv).

<u>4.1.3; 4.2; 4.3.3;</u>

Tables 4.2, 4.3, 4.4, 4.5: Right side is cropped off in pdf version (fine in .html).

EPA's, 2nd response to peer reviewer comments (page 1) states the online version of the docs is the preferred method of viewing the docs. If you want this to be the preferred method, you need to:

- Find some way to help the user reference specific information, by adding page numbers or more levels to the Table of Contents. For example, Section 4 is over 50 pages long and Section 7 is over 200 pages long, making it extremely difficult to provide references to specific information.
- Some of the descriptions in Table 4.2, for example, are extremely long, plus the user has to scroll back and forth for every row in the .html. This makes it very difficult to understand what is in each file. It would be much better to wrap the descriptions in a smaller box, so that users do not have to continuously scroll back and forth.
- The biggest issue is being able to conduct word searches, which works fine with pdf files but the searchfunction for the .html file did not work for me (maybe a Mac problem?)

<u>4.3.3, Table 4.5, page 50</u>

- "epa_size_class" is defined as "Standard" SUV and pickups in Table 4.5, while Fig. 4.3 on page 42 uses "small" and "large" definitions of size class. Need to be consistent.
- More importantly, Table 4.5 does not appear to include any technology information for the baseline vehicles in 'vehcles.csv', which I confirmed when I opened vehicles.csv. Some explanation of how incremental technology benefits and costs over the baseline vehicle are handled should be included.
  - Note that Section 4.3.4 states that technology and cost information is included in 'simulated_vehicles.csv', but no comparable discussion is included in the discussion of baseline vehicles in 4.3.3.

4.3.5.

I found the discussion of selecting the minimum cost package available to be confusing. Might help to explain:

- What each of the orange and blue points in Fig. 4.7 represent – from the documentation, I had little idea why there are so many points, no idea if each point represented a single technology or technology aggregations, etc.
- Why it is appropriate to use the cost-minimizing frontier of the cost cloud.

4.4.3 page 68-69

Top of page 69 states the amortization rate in the demo example is set at 10 years, but 'price_amortization_period' in Table 4.6 is set at 5 years.

4.4.4 p 70

The demo example uses a fixed schedule based on vehicle age for reregistration. It would be helpful to identify the source for the default reregistration schedule in the OMEGA model, as was done for BEV share parameters on page 68.

4.5 p 73

What do the red stars mean on Fig. 4.15? (Fig. 4.14 says "the selected compliance option from the initial Producer-Policy compliance search is shown by a single red star.", but Fig. 4.15 has multiple red stars)

4.5 p 74

Discussion of Fig. 4.16 says nothing about the lower right pane.

4.5

Convergence criteria: Section 4.5 discusses the convergence criteria in many places and page 75 mentions the iteration set limit. However, the documentation fails to discuss what these criteria are or the basis for setting the limits, which should be added.

4.6.1.1., page 80

Transmission Efficiency for both fuel and electricity consumption are stated to be "as set by the user". This implies there are no default OMEGA assumptions.

5., p 84-86

The Batch Input Files are all .py files. This implies that the files used when running with Python are different than the files used when running using the GUI.

- Section 5 (User Guide) should make clear upfront that Section 5 is for Python users, not GUI users.
- Some explanation as to why different files are used with Python would be helpful.
- Still, it is nice to have all the input files listed in one place. Something similar for the earlier .csv input files (in Section 3?) might be helpful.

3.3.1 page 18

Why are both calendar year and model year cert CO_2e plotted? Should explain in the documentation what calendar year and model year are used for and why each is needed.

3.3.1 page 19

Figure 3.8:

- Why does “hauling” have more stringent CO2 targets than “non-hauling” in upper panels (the reverse of the lower panels)?
- Why are there no BEVs in the upper panels

3.3.1 page 24

Caption for Fig. 3.11 should state these are **changes** in stock parameters and that the results **do not include rebound effects.**

3.3.1 page 26

Figure 3.13 has an orange “sales” line in the legend, but not in the graph.

3.3.2 page 31

Figure 3.18 has a “fuel_pretax_cost”, but there is no electricity cost. Electricity is not normally defined as a “fuel”, so if this parameter includes both, should change the name – perhaps “energy_pretax_cost”.

Also, what is “refueling_cost” and why is it different from fuel cost?

3.3.3 page 31

The run log is mixed in with all of the image and .csv output files. Might be better to put it someplace by itself – preferably a new link on the GUI.

GUI – results tab

The Results Tab has not yet been developed. Due to the large number of predefined .png and .csv output files, I would recommend:

- Using descriptive names in the Results tab, such as “Cert and compliance versus year – no action” for the first .png file. As the output files are predesigned, this should be relatively easy to set up and link.
- It would also help to have separate lists for the .png and .csv files.
- For .csv files, the batch-context summary results file should be highlighted somehow.
- Similarly, if there is an overall summary .png file, this should also be highlighted somehow – or perhaps better yet, add a default .png summary figure based on the batch-context summary results file?

.png

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy RC Shares.png – I have no idea what a, b, and c regulatory classes are. Unless I missed this, a description should added to the documentation

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy Stock CO2 Mg.pgn – Title is “Vehicle stock CO2 mg”, but clearly this figure is not total vehicle stock CO2. Need a more accurate title.

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy Stock Gas Gallons.png – Title is “Vehicle stock registered count”, but clearly vehicle stock won’t grow from 10 million in 2020 to 240 million in 2050. Need a more accurate title.

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy Stock kWh

- Should change title from “Fuel” to “Energy”.
- Vehicle stock fuel consumption is about 1.4 kWh in 2050? This isn’t even accurate for per-vehicle consumption. Y-axis label problem?

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy Stock VMT

Title is "Vehicle stock miles traveled", but clearly VMT won't grow from 0.1 mile in 2020 to 2.8 miles in 2050. Need a more accurate title – and y-axis title?

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy V Cert CO2e gpmi Mkt Cat & Cls

Is there a reason why ICE emissions go up after 2028 – especially since the target values do not? (in 2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy V Tgt CO2e gpmi Mkt Cat)

New .png - 2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy V Cost Mkt Cat & Cls – Average vehicle cost is fine, but would also **appreciate an automatic .png file for incremental cost versus 2019 baseline, at least for ICE**

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy V Tgt CO2e gpmi Mkt Cat – The target values for hauling are much lower than the other categories – mislabeled lines?

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy V Tgt CO2e gpmi Mkt Cls

- Target values for hauling much lower than non-hauling – mislabeled?
- There are no lines for hauling or non-hauling BEV (listed in legend)

New .png - I would appreciate an automatic **graph of ICE technology penetration**, at least major tech categories (e.g. MHEV, SHEV, HCR2, Turbo 11, Turbo 12)

<u>.csv</u>

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy_cost_effects.csv

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy_physical_effects

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy_tech_tracking

- There are multiple rows with no distinction beyond 'vehicle_ID' numbers (and 'reg_class_id'?).
  - Is there a file somewhere defining the attributes of each vehicle ID (and reg class)?
  - **It would be helpful if the attributes associated with vehicle ID and reg class could be added to each output file** that generates separate rows based on vehicle ID, to make it easier to interpret the results.
- In these files, the reg classes appear to be **car and truck**. How does that compare with **"hauling" and "non-hauling"** used in the documentation and in the .png files? And why is it different?
- In the policy cost effects file, there are 4 different costs presented for each cost variable (e.g. CH4 and CO2). What do the **25 cost, 395 cost, 3 cost, and 5 cost** columns mean, why do they differ, and why are they all needed?

New .csv - 2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy_new_vehicle_prices

Average vehicle cost is fine, but would also **appreciate an automatic .csv file for incremental cost versus 2019 baseline, at least for ICE**

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy_vehicle_annual_data

This file has index numbers, which I have not seen in any other file.

- How do the index numbers relate to other files when no other file has them?
  - Note that there are 53,856 index numbers, which does not agree with the number of rows in previous files with multiple rows for each configuration.

2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy_vehicles

There are no entries for technology on baseline 2019 vehicles, confirming that there is no technology penetration entered for the baseline fleet. How can incremental technology benefits and costs be calculated without knowledge of baseline vehicle technology?

> **EPA's Response (JG22):** Thank you for the suggested clarifications and updates to the documentation. We will consider revising a future version of the documentation.

There appears to be **no way to compare incremental technology penetration, cost, and GHG reduction versus the baseline vehicles**. This functionality should be added. Or, if it does already exist, the documentation needs to explain how it is done.

> **EPA's Response:** Already addressed earlier.

5.3 Comments Submitted by Dr. Jeremy J. Michalek

5.3.1 General Comments

Thank you for the opportunity to review EPA's OMEGA2 model and provide comments.

In providing feedback on OMEGA2, I first offer feedback on the mathematical problem that OMEGA2 aims to solve; then I offer feedback on the algorithm approach to solving the problem; and finally I offer feedback on a list of additional items. OMEGA2 is a major expansion of scope beyond OMEGA1, and the efforts to make OMEGA flexible to a variety of user modeling choices is excellent and will be useful in informing policy.

I will focus my review on critiques and recommendations that I hope will be most helpful in considering how OMEGA2 or a future version of OMEGA might be generalized, expanded or improved.

5.3.2 Specific Comments

1. Comments on the Mathematical Problem OMEGA2 Aims to Solve

In my understanding, the optimization problem that OMEGA2 aims to solve is to minimize producer generalized cost with respect to the attributes, price, and production volume shares of each (composite) vehicle in the producer's fleet subject to policy constraints, consumer demand constraints, and a constraint that sales-weighted average sale price must equal sales-weighted average baseline price, where baseline price of each vehicle is production cost times a fixed margin.

I think it is helpful to represent the core mathematical problem that OMEGA2 aims to solve on one page. The way I would write this optimization problem in standard form for a single year (using matrix calculus notation where all vectors are in **bold** and all scalars are in italics) is

minimize $c(\mathbf{x})$	minimize producer generalized cost
with respect to $\mathbf{x} = \begin{bmatrix} \mathbf{a} \\ \mathbf{p} \\ \mathbf{v} \end{bmatrix}$	with respect to a vector of decision variables $\mathbf{x}$ that includes the attributes $\mathbf{a}$, prices $\mathbf{p}$, and production volume shares $\mathbf{v}$ for each of the producer's vehicles,
subject to	subject to the following constraints:

$g(\mathbf{a},\mathbf{v}) \leq 0$	• the fleet must comply with GHG standards; $g(\mathbf{a},\mathbf{v})$ is the policy module, which takes attributes and shares as inputs and returns Mg GHG credits short of the standard
$\mathbf{q}(\mathbf{a},\mathbf{p}) - \mathbf{v} = \mathbf{0}$	• production volume shares must equal demand shares; $\mathbf{q}(\mathbf{a},\mathbf{p})$ is the consumer demand model, which takes attributes and prices as inputs and returns a vector of shares, one for each vehicle
$\mathbf{v}^\top\mathbf{p} - \mathbf{v}^\top\mathbf{b}(\mathbf{a}) = 0$	• sales-weighted average price = sales-weighted average baseline price
$\mathbf{a} \in \mathbb{R}^{n\times m}$	• $\mathbf{a}$ is a vector with m attributes for each of the producer's n (composite) vehicles. One of these m attributes is GHG emissions per mile.
$\mathbf{p} \in \mathbb{R}^{n}$	• $\mathbf{p}$ is a vector with one price value for each of the producer's n (composite) vehicles
$\mathbf{v} \in \mathbb{R}^{n}$	• $\mathbf{v}$ is a vector with one production volume share value for each of the producer's n (composite) vehicles
where	where
$\mathbf{b}(\mathbf{a}) = m\mathbf{k}(\mathbf{a})$	• baseline price is production cost $\mathbf{k}(\mathbf{x})$ times a fixed markup (m = *1.5* in OMEGA)

Eq.(1)

Eq(1) is nonconvex nonlinear optimization problem (NLP). Eq(1) could be a nonconvex mixed-integer optimization problem (MINLP) if some of the attributes in the vector $\mathbf{a}$ are discrete, but discrete technologies are represented by a convex hull among a set of discrete points in OMEGA2, which can be represented as a linearly-constrained continuous slack variable, eliminating the discrete variables, and reducing the problem to an NLP. Figure 1 shows how the symbols in Eq(1) map to the diagrams in the OMEGA documentation.

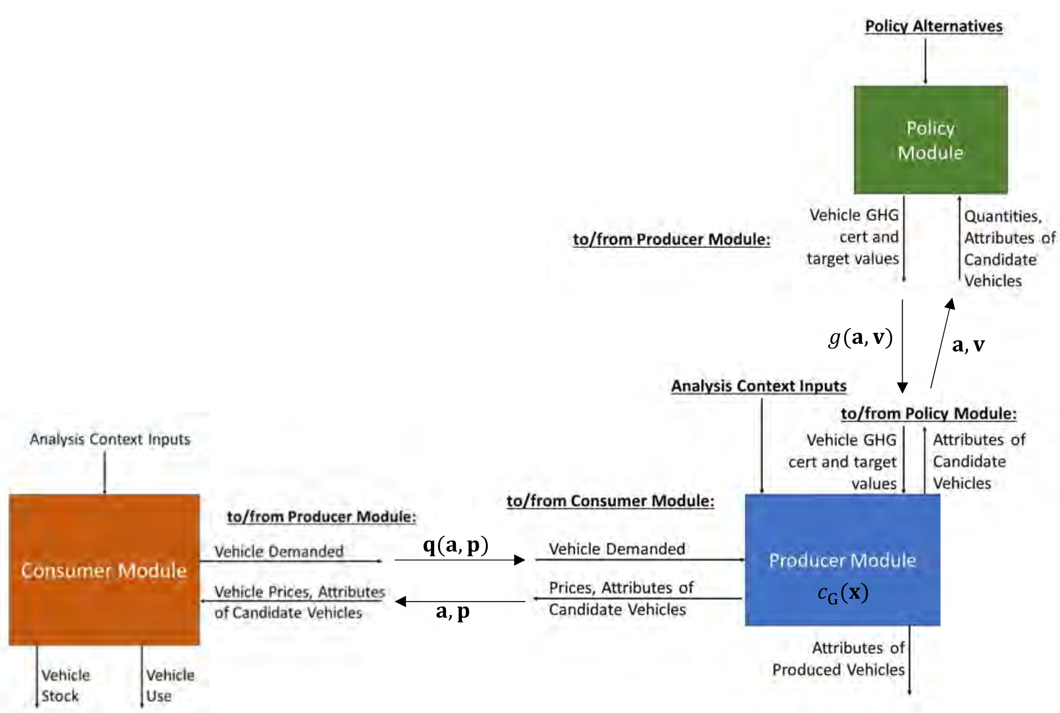

Figure 1: Relationship between Eq(1) and the OMEGA2 documentation

The documentation emphasizes iteration between the producer module and the policy / consumer modules, and the solution algorithm and code are set up this way, but in terms of the mathematical problem that OMEGA2 is fundamentally solving, structurally the policy and consumer modules are just functions that return certification compliance values and a vector of demand values, respectively, as in Eq.(1).

OMEGA2 a major expansion of the prior OMEGA model in scope, and it is designed to be flexible in accommodating different user modeling choices for policy design and consumer demand. These are welcome changes, as they allow modelers to avoid some of the restrictive assumptions of OMEGA1 and potentially account for additional important factors. For example, Whitefoot et al. (2017) find that "The ability of automakers to improve the fuel economy of vehicles using engineering design modifications that compromise other performance attributes, such as acceleration, is not currently considered [in OMEGA1] when setting fuel economy and greenhouse-gas emission standards for passenger cars and light trucks" and "our analysis suggests that acceleration trade-offs play a role in automaker compliance strategies with potentially large implications for both compliance costs and emissions." OMEGA2 provides flexibility for modelers to potentially account for factors like this.

The model also has flexibility for modeling heterogeneous consumers: "users can define sales shares to explicitly consider consumer heterogeneity by defining separate sales share estimates for different consumer groups." This is a particularly useful flexibility, given the difference not only in consumer preferences across the population but also in situational factors that affect willingness to adopt. For example, renters and home owners without off-street parking may be much less likely to adopt electric vehicles than home owners with off-street parking who can install private charging infrastructure, and modeling flexibility can allow users to capture effects like these.

The structure of OMEGA2, however, still does have limitations that restrict its ability to model some important aspects of policy compliance in practice. The most important of these limitations that I identified are all related to restrictions in OMEGA2's ability to model firm profit-seeking compliance behavior.

> **EPA's Response (JM01):** Thank you for the suggestion. We agree that the minimization of generalized cost is not the same as profit maximization. We have incorporated willingness to pay for changes in footprint into the generalized cost definition, so at least in that respect the model now uses an approach for vehicle size changes that is consistent with the objective of maximizing profit.
>
> The modeled average prices of vehicles may change based on the changes in the vehicle technologies applied and associated production costs. But as the reviewer notes, price cross-subsidization between BEV and ICE vehicles is applied in a way that maintains average prices. So, while the modeled profit margins for BEV and ICE vehicles are allowed to vary within OMEGA, for this version of the model we did not attempt to implement free pricing of vehicles. At this time, we have not identified a model specification for the relationships between vehicle prices, attributes, and quantities that could be used to provide a computationally tractable solution within the iterative search structure of the model.
>
> We will continue to consider the possibility of including a free-pricing optimization algorithm in a future version of the model.

1. **Firm Pricing Strategy and Profit Maximizing Behavior**

   Recommendation 1: Implement a generalization of OMEGA2's structure that will allow users to model profit-maximizing behavior by including free pricing of the vehicles during the compliance search, rather than fixed margins.

   ***Rationale*:** The model structure requires that the sales-weighted average vehicle price is equal to the sales-weighted average baseline price, which is production cost times a fixed markup for each vehicle.

This restriction prohibits producers from preferring technologies that sell at higher margins (unless it is impossible to satisfy regulation without them).

- The document emphasizes that the "assumption that producers will attempt to minimize their generalized costs is consistent with a producer goal of profit maximization," but I believe this is only true under restrictive conditions. In the appendix I provide a simplified Matlab code to solve for (1) minimum production cost, (2) minimum producer generalized cost, and (3) maximum profit subject to (a) average price constraints or (b) no price constraints using a multinomial logit model of demand. The solutions to (1a), (1b), (2a), (2b), (3a) and (3b) are all different, suggesting two things: (i) minimizing producer generalized cost is not necessarily consistent with profit maximization and (ii) fixing average price, using a fixed margin, restricts solutions, leading to less-profitable solutions.
- When consumer willingness to pay (WTP) for some products is higher than production cost and WTP for other products is comparable to or lower than production costs, minimizing producer generalized cost (which will prefer the lower cost products) may not be consistent with profit maximization behavior (which will prefer the higher margin products). In order to model profit-maximization behavior, it is necessary that (1) prices are treated as free variables without constraining margins to a pre-determined average, and (2) negative revenue is included in producer generalized cost. The latter is possible in OMEGA2's current structure, depending on user-specified functions, but the former is not.

Recommendation 2: Advise users that when looking to model profit-maximizing behavior, producer generalized cost should include total production cost minus total revenue for the fleet, rather than willingness-to-pay.

EPA's Response (JM02): The OMEGA model's use of WTP values in the generalized cost function is limited to the fuel costs considered over a specified number of years after vehicle purchase, and vehicle footprint. We agree that cases where the other vehicle attributes vary dramatically between the alternatives, that the willingness to pay values for fuel costs and footprint may also vary. In the OMEGA model, the other vehicle attributes are generally held constant, except for vehicle price. Even considering the difference between ICE and BEV powertrain types, the other vehicle attributes related to performance and capability are assuming to be similar. Under these conditions, we believe it is appropriate to include an absolute WTP value for footprint and fuel cost.

Rationale: The OMEGA2 documentation states that WTP can be embedded in the producer generalized cost function:

> "While the producer's modeled objective function is cost minimization, the term 'cost' is used generically here, as it is not necessarily the case that the lowest production cost option is the best option for the producer. Consumer willingness to pay for a particular vehicle attribute can result in another choice if the producer expects that the additional production costs can be more than offset by a higher price. Here, the term producer generalized costs is defined as the net of vehicle production costs and the producer's view of consumer's willingness to pay for that vehicle."

However, in (random utility) consumer choice models, WTP is a *relative* measure. There is no such thing as "WTP for product A" because demand for product A depends on the attributes and prices of competitor products as well. What these models estimate is WTP for a *change* from attribute level 1 to attribute level 2. Thus, WTP for a product is always relative to a reference point (e.g.: WTP $x more for product A than product B, given their attributes). Further, WTP is an average value – it really measures the iso-demand price equivalency of a change in attributes. For example, if WTP for the attributes of product A is $x more than WTP for the attributes of product B, and if product A is priced at $x more than product B, then share for products A and B will be equal. If product A is priced at $(x+1), then share for product A will be less than product B. This all matters because (at least using the discrete choice model paradigm) there is no way to specify a single "WTP" value for a single vehicle in the producer generalized cost function independent of all other vehicles.

2. Firm Sales Volume Strategy

***Recommendation 3*: Implement a generalization of OMEGA2's structure that allows users to run profit-maximizing cases that consider strategic pricing and overall sales volume in producer decisions.

EPA's Response (JM03): We have not included strategic vehicle pricing by manufacturers to mitigate the effect on sales or maximize overall profits. We agree that the minimization of generalized cost is not the same as profit maximization. We have incorporated willingness to pay for changes in footprint into the generalized cost definition, so at least in that respect the model now uses an approach for vehicle size changes that is consistent with the objective of maximizing profit.

Rationale: The model structure allows the producer to consider only the effect of market *share* on its generalized costs and does not allow the producer to consider the effect of overall sales volumes nor to strategically adjust average prices. This prohibits producers from adjusting to changes that may affect overall volume, the way producers seeking to maximize profit would in practice.

- For example, a more stringent policy may increase vehicle costs overall and reduce overall demand for automobiles. A producer observing this may choose to lower prices to mitigate the effect on overall sales volume, if it is profitable to do so, but OMEGA2 does not allow this.
- It is understandable why EPA may choose to make this assumption, since models that do allow firms to strategically seek to change average prices and overall sales volume can potentially produce solutions far from today's observed sales patterns and extrapolated far from data on which demand models have been built (e.g.: firms setting prices at infinity to generate zero sales when generalized costs are positive; monopolistic producers pricing much higher than oligopolistic producers, etc.). However, there may be important differences between the way firms respond to regulation when they can consider effects of their choices, including average pricing, on overall sales volume. OMEGA2's assumption represents a potentially significant gap between the problem that OMEGA2 solves and the behavior of profit-maximizing firms.

3. Accounting for Competition:

***Recommendation 4**:* Clarify how OMEGA2 handles multiple producers competing for market share, if at all, and should consider implementing functionality that would allow users to model multiple firms in equilibrium.

EPA's Response (JM04): Thank you for the suggestion. In the latest version of the OMEGA model, we have implemented a "credit market efficiency" (CME) parameter, which allows the user to specify a degree of market inefficiency in the credit trading assumptions. Specifically, this involves a 2-pass modeling approach, where in the first pass, manufacturers are considered to take full advantage of credit trading to minimize generalized costs. The achieved CO2 values from the first pass are used in a second modeling pass, where manufactures are run individually. Manufacturers that have CO2 levels above the CO2 standard (i.e., target) in the first pass will attempt to achieve CO2 levels closer to the CO2 standard in the second pass. While manufacturers that are at or below the CO2 standard in the first pass will retain that level in the second pass. As a result, some credits for the overall industry will go unused. The amount of unused credits will depend on the specified credit market efficiency value. We did not implement profit-seeking behavior.

Rationale: The demo uses a single monopolist producer with a fleet of products. In practice, multiple producers compete with one another for market share, and competition drives prices down. The simplicity of a single producer model can be helpful; however, the optimal way for a monopolist to respond to regulation may differ substantially from the equilibrium solution of an oligopoly responding to regulation. The documentation states that "The user can choose to model the producers either as an aggregate entity with the assumption that compliance credits are available in an unrestricted market (i.e. 'perfect trading'), or as individual entities with no trading between firms," but it is not clear how equilibrium among competing firms is handled. There is no reference to equilibrium among firms in the documentation. If OMEGA2 is generalized in a way that allows it to model profit-seeking behavior, it may be important to simultaneously allow it to model competition among producers.

4. Modeling Multi-Year Producer Strategy:

Recommendation 5: Pursue a revision of OMEGA2 in which firms can make strategic decisions considering multiple years at a time and allowing for users to model dynamic factors such as compliance strategy, volume-based production cost, and volume-influenced consumer demand.

Rationale: The OMEGA2 model structure solves Eq(1) for each time step (year) separately. This has a number of implications.

- **Compliance:** In OMEGA2, firms attempt to achieve compliance in every time step, prohibiting firms from strategically banking credits in some years to use in future years. This may result in overestimating the cost to producers of a policy because it limits the options available to producers to comply with the policy. EPA states that "In a future revision, we plan to consider incorporating producer decisions that are intentionally under- or over-target based on the assumption that producers make strategic decisions looking beyond the immediate present to minimize generalized costs over a longer time horizon." An effort to integrate this option would be worthwhile.

EPA's Response (JM05): Thank you for the suggestion. We have implemented logic in the latest version to prioritize historical banked credits, so that, if possible, those credits will be used before expiring. We have also implemented logic so that if a manufacturer is unable to meet the CO_2 target each year, that the manufacturer will aim to be under the CO_2 target in subsequent years, until that deficit is offset using credit carry-back. We have not implemented logic that would allow a manufacturer to reduce total costs over a multi-year timeframe by using strategic over- or under- target performance in particular years.

- **Production Cost and Learning:** OMEGA2 permits technology costs to decline over time exogenously, as defined in input files, but the structure does not allow for experience-based learning, where costs decline as a function of cumulative production volume. Experience-based learning could be an important factor in firm compliance strategy, where firms may choose to produce unprofitable EVs today in order to reduce costs so that EVs are more profitable tomorrow. Arthur Yip's Carnegie Mellon Dissertation (Ch4) provides an example of strategic firm equilibrium under GHG regulation and experience-based learning where firms solve for multiple years of decisions simultaneously. When expanding OMEGA2 to address multi-year decision strategy in (a), EPA should consider whether the model can adopt user-provided endogenous technology costs that depend on volume. Such flexibility could accommodate volume-based cost reductions from economies of scale as well as learning and other factors.

EPA's Response (JM06): Thank you for the suggestion. For most technologies within OMEGA, while learning is applied on a year-over-year basis, it is meant to reflect the learning-by-doing phenomenon or, in effect, volume-based learning. This should not be confused with the concept, reflected in the term "time-based learning," that EPA introduced in a past analysis but subsequently rejected as an inappropriate characterization of the learning-by-doing phenomenon. The one exception is battery costs, where in the latest version of OMEGA we have implemented learning-by-doing endogenously as the reviewer suggested.

- **Consumer Demand and the Neighbor Effect:** Consumer demand for new technologies can increase when they observe these technologies being adopted by others (Mau et al., 2008). If OMEGA2 were flexible enough so that the consumer demand function could consider cumulative prior sales of each technology, current share of the fleet, or other such factors, a multi-year producer strategy may consider how investment in new technologies today (like EVs) could change future consumer demand.

If EPA were to generalize OMEGA2 to address the recommendations above, the problem that OMEGA2 solves for a single producer might look more like Eq(2), with changes in blue (credit banking and trading could be added as additional variables, not shown):

EPA's Response (JM07): Thank you for the suggestion. In the current version of OMEGA, the share-weight 'S' curves for BEV and ICE demand are exogenous. We will consider making the 'S' curve a function of BEV volume in a future version.

maximize $\Pi(\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_T)$	maximize discounted expected future profits (which could be reduced to minimizing producer generalized costs if the user sets revenues appropriately (e.g.: to zero))
with respect to $\mathbf{x}_t = \begin{bmatrix} \mathbf{a}_t \\ \mathbf{p}_t \\ \mathbf{v}_t \end{bmatrix} \forall t$	with respect to decision variables $\mathbf{x}$ that include the attributes $\mathbf{a}$, prices $\mathbf{p}$, and production volume $\mathbf{v}$ of the producer's vehicles across all time steps t,
subject to	subject to the following constraints:
$\mathbf{g}(\mathbf{a}_t, \mathbf{v}_t\ \forall t) \leq \mathbf{0}$	• the fleet must comply with GHG standards; $\mathbf{g}(\mathbf{a}, \mathbf{v})$ is the policy module, which takes attributes and shares as inputs and returns a vector of Mg GHG credits in excess or short of the standard across all years t
$\mathbf{q}_t(\mathbf{a}_t, \mathbf{p}_t) - \mathbf{v}_t = \mathbf{0}\ \ \forall t$	• every year t production volume ~~shares~~ must equal demand ~~shares~~; $\mathbf{q}(\mathbf{a}, \mathbf{p})$ is the consumer demand model, which takes attributes and margins (price multipliers) as inputs and returns a vector of ~~shares~~ sales volumes, one for each vehicle
$\mathbf{a} \in \mathbb{R}^{n \times m}$	• $\mathbf{a}$ is a vector with m attributes for each of the producer's n (composite) vehicles. One of these m attributes is GHG emissions per mile.
$\mathbf{m} \in \mathbb{R}^{n}$	• $\mathbf{m}$ is a vector with one markup value (price multiplier) for each of the producer's n (composite) vehicles
$\mathbf{v} \in \mathbb{R}^{n}$	• $\mathbf{v}$ is a vector with one production volume ~~share~~ value for each of the producer's n (composite) vehicles

Eq.(2)

A model with only a single producer, as above, would be a monopolist, which may tend produce optimal solutions with substantially higher prices than today's competitive auto market. An oligopoly could be modeled using multiple producers to find a Nash equilibrium. Nash equilibria could be solved numerically either (1) by sequentially iterating across the producers until convergence or (2) by solving for the first order (KKT) conditions of Eq.(2) simultaneously across all producers. For example, see Figure 5-6 of Shiau and Michalek (2007), provided below.

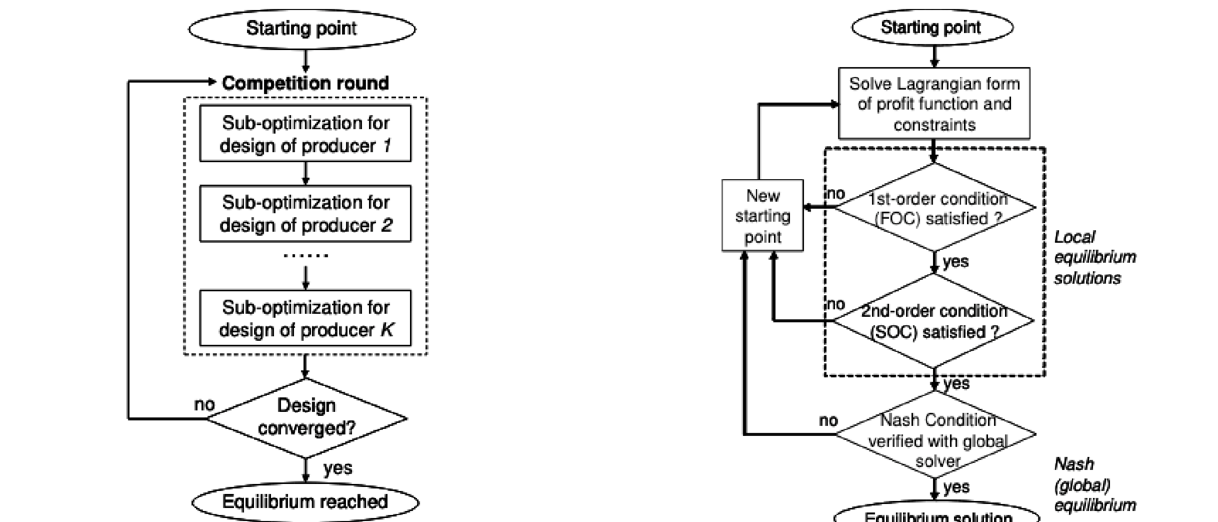

Figure 5: Flowchart of the sequential optimization algorithm

Figure 6: Flowchart of Lagrangian FOC algorithm

Figure 2: Figures from Shiau and Michalek (2007) showing two approaches for finding Nash equilibria among competing producers.

An important risk in considering expanding scope of OMEGA2 to model equilibrium behavior is that equilibria may not exist or may be nonunique for some problems.

2. Comments on OMEGA2's Solution Approach

The approach to solving Eq(1) in OMEGA2, as I understand it, is to discretize the space of the decision variables using user-defined resolution (which is iteratively refined in the consumer module iteration) and test all combinations using full factorials in the $\mathbf{a}, \mathbf{v}$ subspace and in the $\mathbf{p}$ subspace. Specifically,

1. Solve minimize $c(\mathbf{x})$ with respect to $\mathbf{a}, \mathbf{v}$ subject to $g(\mathbf{a}, \mathbf{v}) \leq 0$ (given $\mathbf{p} = m\mathbf{k}(\mathbf{x})$).
   First a full factorial sweep over $\mathbf{a}_\mathrm{G}$ and $\mathbf{v}$ is executed, where $\mathbf{a}_\mathrm{G}$ is a vector that contains all of the elements of $\mathbf{a}$ corresponding to GHG emission levels of the vehicles (there may be other attributes in $\mathbf{a}$ that affect demand but do not affect the policy module). $\mathbf{v}^\top\mathbf{k}(\mathbf{x})$ and $g(\mathbf{a}, \mathbf{v})$ are calculated for each point, and among all the results the point selected is the one that minimizes $\mathbf{v}^\top\mathbf{k}(\mathbf{x})$ subject to $g(\mathbf{a}, \mathbf{v}) \leq 0$ (within tolerance).

2. Solve $\mathbf{q}(\mathbf{a},\mathbf{p}) = \mathbf{v}$ and $\mathbf{v}^\top\mathbf{p}(\mathbf{x}) = m\mathbf{v}^\top\mathbf{k}(\mathbf{x})$ with respect to $\mathbf{p}$ for fixed $\mathbf{a}$ and $\mathbf{v}$.
   Next, a full factorial sweep over cross-subsidy multipliers is executed (with iteratively tighter resolution and iteratively smaller domain bounds, $\mathbf{q}(\mathbf{a},\mathbf{p})$ is calculated for each point using the consumer demand model, and among the results
   a. If any of the points solves $\mathbf{q}(\mathbf{a},\mathbf{p}) = \mathbf{v}$ and $\mathbf{v}^\top\mathbf{p}(\mathbf{x}) = m\mathbf{v}^\top\mathbf{k}(\mathbf{x})$ within tolerance, go to step 4.
   b. If not, take the point $\mathbf{q}_{\text{BEST}}$ with the smallest error ($\|\mathbf{q}(\mathbf{a},\mathbf{p}) - \mathbf{v}\|$ and $\|\mathbf{v}^\top\mathbf{p}(\mathbf{x}) - m\mathbf{v}^\top\mathbf{k}(\mathbf{x})\|$) and go to Step 3.

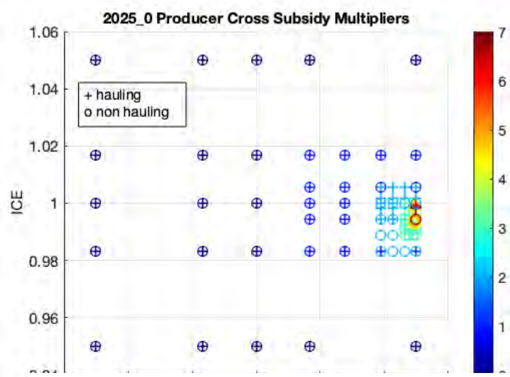

Figure 3: Full factorial sweep grid search implemented in OMEGA2

3. Solve minimize $c(\mathbf{x})$ with respect to $\mathbf{a}$ subject to $g(\mathbf{a},\mathbf{v}) \le 0$ for fixed $\mathbf{v}$ ($\mathbf{p} = m\mathbf{k}(\mathbf{x})$).
   If Step 2 failed to find a solution, then Step 1 is repeated with $\mathbf{v} = \mathbf{q}_{\text{BEST}}$ found in Step 2: A full factorial over $\mathbf{a}$ is executed with fixed value for $\mathbf{v}$, and among all the results the point selected is the one that minimizes $\mathbf{k}(\mathbf{x})$ subject to $g(\mathbf{v},\mathbf{a}) \le 0$ (within tolerance). Return to Step 2 and iterate until a solution is found or an iteration limit is reached.

4. The composite vehicles used in the iterations are decomposed into individual vehicles.

My primary comment about this solution approach is (1) the potential for it to produce suboptimal solutions and (2) the implications of suboptimal solutions for OMEGA's purpose of comparing policies.

Suboptimality Concern #1

It is not clear to me under what conditions this algorithm can find the solution to Eq(1). Decomposing the problem with variables $\mathbf{a},\mathbf{p},\mathbf{v}$ into (1) a subproblem in the $\mathbf{a},\mathbf{v}$ space and (2) a subproblem in the $\mathbf{p}$ space is possible, but decomposition methods typically require certain types of coordination strategies to ensure convergence to a system optimum.

In OMEGA2's approach, if the solution to Step 1 produces values for $\mathbf{a},\mathbf{v}$ such that a vector $\mathbf{p}$ exists that solves Step 2, the algorithm will accept this as the solution, even if the combination $\mathbf{a},\mathbf{p},\mathbf{v}$ together do not minimize the producer's objective. Such a point will only be known to be a system optimum (solving Eq(1)), in general, if the producer's objective does not change across all permitted values of vehicle prices. I believe OMEGA2 aims to impose exactly this restriction by requiring that sales-weighted average prices are equal to baseline sales-weighted average prices at a *1.5* × margin. EPA describes this as "forcing any cross-subsidization strategies to be revenue neutral"; however, this requirement is restrictive, as discussed previously, and any future generalizations of OMEGA2 permitting producers to adjust prices in more flexible profit-seeking ways would violate this condition, leading the OMEGA2 algorithm to produce suboptimal solutions.

> **EPA's Response (JM08):** Please see our responses to reviewer comment JM01 about the modeling of profit maximizing behavior.

Suboptimality Concern #2

The iteratively refined grid search approach is not guaranteed to find a solution if one exists, except as the resolution approaches infinity. Consider the hypothetical example below. The search grid here (for producer cross-subsidy multipliers) is used to search for points that satisfy two constraints within tolerance: (1) market share proposed by the producer matches market share resulting from the consumer model and (2) sales-weighted average price matches the reference average price. In the figure, I create one hypothetical curve representing the set of points that satisfies each of these conditions. The shaded area surrounding each curve represents the tolerance. The intersection of these curves represents the point that satisfies both conditions. The iteratively refining grid search strategy will miss the solution in this case because among the initial points tested, the point at [1.05,1] is closest to satisfying both conditions, so that will be the center point of the refined grid, but the actual solution is closer to [0.97,1], which will be missed by the refined grid with reduced bounds in this case. This issue of iteratively-refined grid search missing solutions is exacerbated in higher dimensions.

EPA's Response (JM09): Thank you for the comment. We have made revisions to search algorithm to implement the cross-subsidy search by market class (body style, currently), rather than attempting to search multiple market classes simultaneously as was the case in the demo. Separating the searches simplifies the search space and improves the search results. Our testing has shown expected results.

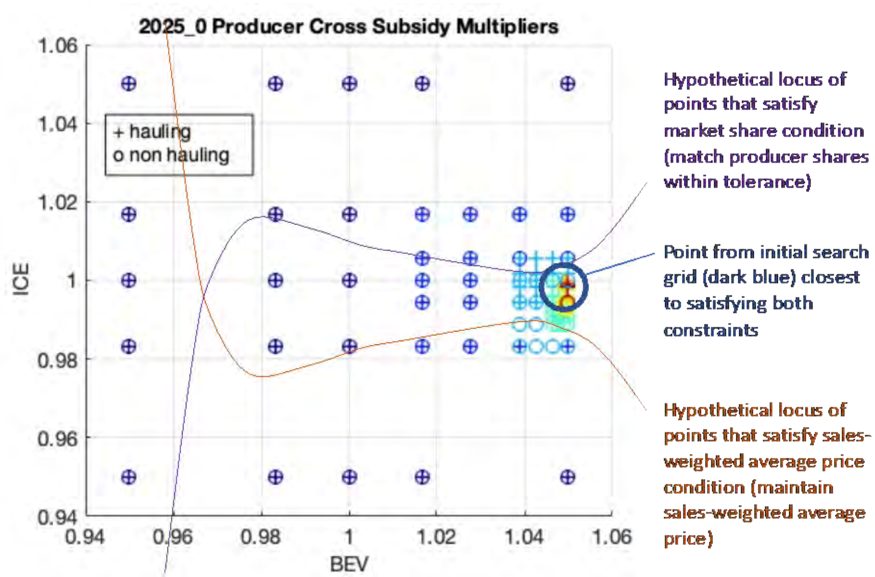

Figure 4: Hypothetical example where the iteratively-refined grid search approach will concentrate on the right-hand side of the search space because the grid point there is closest to satisfying the two equality constraints simultaneously within tolerance (represented by the shaded area), even though the solution is actually on the left-hand side of the search space.

Suboptimality Concern #3

A third concern is that the OMEGA2 search algorithm uses iteration limits as termination criteria, and it carries forward results from prior years when the algorithm fails to converge within iteration limits. This is another reason why the OMEGA2 search algorithm could return suboptimal solutions.

EPA's Response (JM10): The algorithm has been revised so that the model will always converge between the producer and consumer. Please see our response to reviewer comment JM17.

Implications of Suboptimal Solutions

For all of the above reasons, my concern is that if the OMEGA2 algorithm for solving Eq(1) produces suboptimal solutions, the solutions may be more suboptimal for some policy scenarios than others, making comparisons of policies unreliable and potentially biased in systematic ways. For example, if the OMEGA2 algorithm is systematically better at solving problems with policies of type A than it is at solving problems with policies of type B, then users may obtain results suggesting that policy type A produces better outcomes than policy type B, even if policy B actually has a superior true system optimum (see figure below). This possibility could lead users to make conclusions about which policies are best based on how good the algorithm is at solving each policy case, rather than based on which case actually has better outcomes.

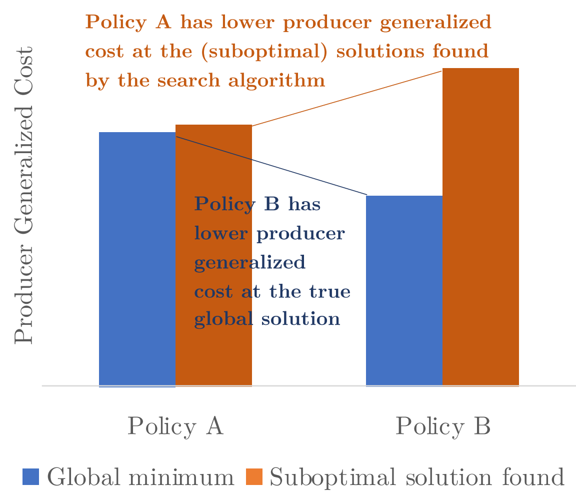

Figure 5: Hypothetical case where Policy B has lower producer generalized cost at the true system global optima, but the search algorithm finds a better suboptimal solution for Policy A than for Policy B.

Alternative Search Algorithm Options

Alternative approaches to solving Eq(1) for global system optimality that may mitigate the risk of suboptimal solutions include

1. **Conduct search in the entire $\mathbf{x}$ space simultaneously**, rather than decomposing the problem as OMEGA2 does. Options include:
   - **Deterministic Global Optimization:** If the functions (c, g, and $\mathbf{q}$) can be restricted to algebraic forms, a modern convexificiation-based branch-and-bound algorithm, such as BARON, could be used to guarantee global solutions to nonconvex problems within a specified tolerance (the algorithm requires the functions to be available in algebraic form in order to generate a series of valid convex relaxations of nonconvex functions). This approach has the key advantage that global optimality can be guaranteed, avoiding concerns about biased comparisons due to algorithm suboptimality. The key disadvantages are (1) functions must be algebraic and avoid trigonometric functions and (2) the computational efficiency of algorithms like BARON can depend on the functional form.
   - **Multistart Local Optimization:** If the functions (c, g, and $\mathbf{q}$) cannot be restricted to algebraic forms but the optimization variables are all continuous, efficient NLP local solution algorithms, such as SQP with BFGS, could be used to solve the problem for a local solution, and an array of SQP-BFGS starting points (such as the initial search grid sweep in the current approach) could be used to search for the best local minimum. The key advantage of this approach is that it can typically efficiently produce local solutions within tight tolerances, and with a sufficient array of starting points it will typically find the global solution. The key disadvantage of this approach is that it does not guarantee global optimality, and NLP

algorithms are not as robust as LP algorithms, depending on the problem formulation and scaling, so there may be cases where they could stall or fail to produce local minima.

- **Grid Search:** EPA could extend its current full-factorial grid search approach on discretized decision variables but conduct the grid search simultaneously in the full $\mathbf{x}$ space rather than decomposing the space into an $\mathbf{a}, \mathbf{v}$ search and a separate $\mathbf{p}$ search. This approach would approach system optimality as the resolution approaches zero, but it would still leave open the possibility of suboptimal solutions in practice due to Suboptimality Concern #1 and #2, and scalability will be limited as dimensionality increases.
- **Other Gradient-Free Methods** could be used to search the full $\mathbf{x}$ space, such as response surface methods, pattern search, evolutionary algorithms, or other methods. These methods generally do not guarantee system optimality (except as iterations approach infinity), so the disadvantages to these approaches are similar to the current OMEGA2 approach of iteratively refining grid search.

2. **Use formal decomposition algorithms**: The problem can be decomposed similarly to OMEGA2 but using a method guaranteed to produce system optima. The literature on multidisciplinary design optimization covers a variety of decomposition approaches and algorithms. Khajavirad and Michalek (2009) provide one relevant approach for finding system optima while decomposing nonconvex MINLPs into quasi-separable subproblems using BARON to globally solve the subproblems in order to improve efficiency. A similar approach could be used for OMEGA2 to guarantee global optima while decomposing the problem into compliance and market subproblems if the producer generalized cost, consumer demand, and policy compliance functions can all be written algebraically.

Recommendations

1. ***Recommendation 6*:** Flag suboptimal results prominently.

   When comparing across policy scenarios, the graphical outputs do not indicate whether differences in results across the scenarios are due to differences in the producer solutions across scenarios or differences in the algorithm's performance across scenarios. I suggest that the results should prominently differentiate between results where the OMEGA2 algorithm can be confident that the result presented is a system optimum vs. results that may be suboptimal (such as when iteration limits are reached).

EPA's Response (JM11): The algorithm has been revised so that the model will always converge between the producer and consumer. Please see our response to reviewer comment JM17.

2. ***Recommendation 7*:** Consider an alternative solution approach.

   I recommend EPA assess whether an alternative solution approach can be used that will consistently return system optima and that can be flexible to variations in modeling assumptions recommended in Section 1 of this review.

EPA's Response (JM12): Thank you for the comment. We have considered this approach but determined that it is to numerically intensive to simultaneously search compliance and pricing strategies as a full cross-subsidy search would have to occur at every point in the search. As a compromise, in the latest version of the model we have added additional dimensions to the pricing search, by body style, and producer-consumer shares converge one market class at a time, rather than all at once as in the provided demo. This provides a more incremental approach to taking consumer shares and allows the producer to adjust their production decisions as the process proceeds. In the limit, for a large number of market classes, this would approximate a simultaneous search.

a. **Deterministic Global Optimization:** The most promising approach, in my estimation, may be to use BARON (which has a Python interface), and this is what I recommend pursuing. The applicability of BARON will depend on the ability to represent functions algebraically (or logically with disjunctions), and the practical performance of BARON will depend on the form of the nonconvex functions, so these must be considered.
b. **Deterministic Global Optimization with Decomposition:** I recommend that EPA also consider continuing to decompose the problem into compliance and market subproblems for global bounding using BARON to potentially improve the efficiency of global search, as in Khajavirad and Michalek (2009).
c. **Deterministic Local Optimization with Multistart:** Alternatively, if the functions cannot be written algebraically or BARON is otherwise not a good fit, I recommend the gradient-based local NLP approach (SQP with BFGS) using multistart to search for global minima. Such an approach will have much tighter tolerances than the current grid search approach, may be more likely to consistently find the global minimum, and may reduce algorithm artifacts in the results (such as credits earned and spent as a pure artifact of algorithm search tolerance).
d. **Expanded Grid Search:** Performing the current OMEGA2 grid search approach in the full $\mathbf{x}$ space, rather than in separate decomposed spaces, is another alternative to address Suboptimality Concern #1, though it may not address concerns #2-3, and computational cost may be prohibitive as dimensionality grows.

Other Recommendations

1. Producer Generalized Cost

Recommendation 8: Update documentation to clarify and ensure consistency in definitions of producer generalized cost and clarify for the user what it can and cannot capture. Clarify that users need to include fleet production cost less fleet revenue (not WTP) in order for the objective to be aligned with (price constrained) profit maximization.

EPA's Response (JM13): Thank you for the suggestion. We will consider updating the documentation in a future version.

Rationale: Producer generalized cost is described a varied of ways in the document that seem imprecise or inconsistent – or at least could be clarified.

Producer generalized cost as profit

- "*The term producer generalized costs is defined as the net of vehicle production costs and the producer's view of consumer's willingness to pay for that vehicle*." This definition implies that the value consumers pay for the vehicle is included, suggesting that producer generalized cost will be negative for a profitable product (sale price > production cost). But this is not how the demo example works.
- "*The total of the monetary expenses of bringing a product to the consumer, and the value the producer expects can be recovered from consumers at the time of purchase*." This statement has the same apparent implication as the prior.
- "*This assumption that producers will attempt to minimize their generalized costs is consistent with a producer goal of profit maximization.*" This statement again seems to sound like the prior two.

Producer generalized cost as production cost plus fuel cost

- "*In the demo example, producer generalized costs represent the marked-up production costs, plus a price modification (i.e. an external subsidy incentive, if applicable), plus the portion of fuel costs that the producer assumes to be valued by the consumer at the time of purchase.*" This statement appears to match how producer generalized cost is handled in the demo. In contrast to the "value consumers pay" described above, in this statement it is more like production cost plus a relative *negative* value to consumers of future fuel costs.
- "*producer generalized costs … include 5 years of fuel costs at 15,000 miles per year that the producer assumes are valued by consumers at the time of purchase (as defined in the analysis context input file 'producer_generalized_costs.csv'.) Note that the producer generalized costs are higher than the production costs, and also form a cloud with a different shape than the blue production cost cloud.*" This statement is a specific case of the prior statement.

2. Convex hull cost curve:

I have three observations / recommendations about the way the cost curves are handled in OMEGA2:

Convex hull approximations

Recommendation 9**:** Review the state of the art of convex hull algorithms and determine whether OMEGA2 can generate cost curves that are precise convex hulls, rather than approximate affinity solutions.

EPA's Response (JM14): Thank you for the suggestion. We are using the 'affinity factor' to define a reasonable representation of the frontier, without requiring a large number of points to define the frontier, and thus increase the computational requirements. The structure of the model makes it possible to implement alternate approaches for approximating the frontier without necessarily requiring major modifications to the code. We will continue to consider whether any alternate approaches can improve the current model's identification of the frontier, and at the same time maintain or improve the model's computational efficiency. Conceptually, the frontier is meant to be a plausible frontier, more than a literal frontier. In reality, every point in the cloud has some uncertainty associated with it, both in terms of cost and CO2 performance. A "frontier" that cuts through the cloud of points can be considered to be within the reasonable range of values supported by those points.

Rationale**:** The documentation shows examples of approximate convex hulls that are not accurate convex hulls. For example, the figure below shows a cost curve that leaves out at least six inferior points. The documentation describes an "affinity" parameter that the user can use to adjust this curve, and I did not have time within the review period to understand this approach fully, but the affinity approach appears to be able to generate nonconvex curves, depending on the affinity parameter value, whereas the convex hull is well defined and deterministic – it is not subject to parametric variation. I am not very familiar with convex hull construction algorithms, but I know there are a variety of efficient convex hull identifying algorithms dating back to the 1970s, and because OMEGA2 has a finite point cloud, it seems like it should be computationally fast to identify the convex hull in 2D, which will simply be a polygon (the epigraph). If OMEGA2 uses an approach that generates an approximate cost curve that is not the convex hull, how can EPA be sure that the approximation is "good enough" or even "convex enough"? Might there be systematic biases where the curve is better at representing some areas of the space than others?

Pareto set vs. convex hull

Recommendation 10: Use the convex hull of the Pareto points as the cost curve rather than the convex hull of the full set of the points.

EPA's Response (JM15): Thank you for the suggestion. In the latest version of the model, we have added a user option which will truncate the non-optimal points that are more costly than other points with lower emissions. This truncation is the default behavior.

Rationale: It is not clear to me why OMEGA2 needs the non-Pareto portion of the convex hull. The left three points of the convex hull represent the Pareto frontier, whereas the four points to the right (circled in red) are all dominated and will never be optimal solutions (except if there are additional attributes not shown – see next bullet).

Vehicle attributes

Recommendation 11: Revise documentation to make clear to users the requirements for which factors must be included in their producer generalized cost estimates in order for the convex hull cost curve approach to be a valid way to generate optimal solutions.

EPA's Response (JM16): The current default producer generalized cost includes vehicle production cost, and the fuel cost portion and valuation of footprint that producers assume consumers consider in their purchase decision. A user could define any other elements of producer generalized cost. The search algorithm will attempt to minimize the generalized cost with whatever definition is used.

Rationale: Use of convex hull cost curves can be a computation-saving representation, since the search algorithm need not search the entire point cloud. However, if consumers have willingness to pay for attributes of the technologies in the point clouds other than CO2e, then these convex hull or Pareto curves may not identify optimal technologies. For example, suppose the technology package circled in teal, which is inferior to other technologies on producer generalized cost and CO2e metrics alone, has other attributes that are highly valued by consumers (e.g.: rapid acceleration). The curve can then not necessarily identify which technology packages will be optimal unless the producer generalized cost captures consumer willingness to pay for such attributes.

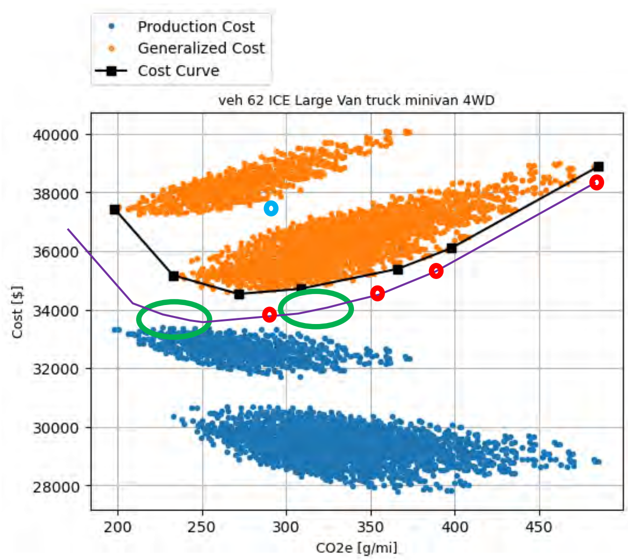

Figure 6: Illustration of three issues with the cost curves: (1) the cost curves used by OMEGA2 (black) can be inferior to the convex hull (purple) and leave out superior solutions, highlighted in green; (2) the convex hull includes points that are non-Pareto and will

never be part of an optimal solution (red circles) unless (3) the optimal solution may not lie on the convex hull if technology packages affect other attributes besides CO2e that influence consumer willingness to pay (e.g.: light blue circle).

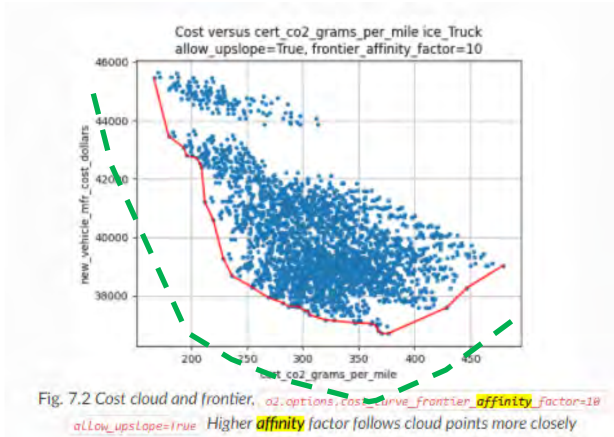

Figure 7: Figure from the documentation showing that the affinity approach can generate nonconvex results that are not the convex hull. The convex hull is shown in green.

3. Communication of credit banking results

Recommendation 12: Prominently identify results that are due to algorithm tolerance or non-convergence separately from those that are meaningful results. In particular, use a different linetype or color for credit transfers that are due to algorithm tolerance alone, or provide the option to suppress spurious results like this from the graphical output.

EPA's Response (JM17): In the latest version of the model, we have continued to refine the search algorithm so that a convergence between the producer and consumer is always achieved. Specifically, as a last resort, if the producer is not able to find a product mix, pricing, and application of technology that consumer will accept while meeting the producers desired Mg CO2 compliance target, then the producer reverts to the closest possible solution that is acceptable to the consumer, while relaxing the Mg CO2 constraint. As a result, instead of considering whether the producer and consumer have converged or not, the model outputs should be viewed in terms of whether the compliance targets are achieved or not.

Rationale: It would be useful if the presentation of results would differentiate between credit carryover that is due to algorithm tolerance vs. credit carryover that is due to inability to comply (or, in a future version, strategic dynamic compliance). Much of the green curve credit carryover in the demo results is just an artifact of the search algorithm and the resolution/tolerance used, not representative of how automakers would be expected to respond to the policy.

If EPA follows my recommendation of using deterministic global search algorithms or local NLP algorithms, this issue may be a moot point because tolerances can be set much tighter than with grid search.

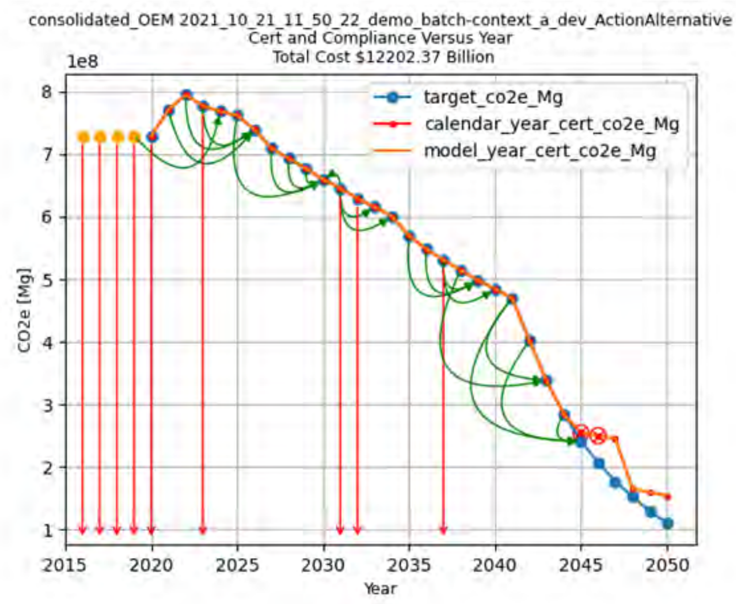

Figure 8: Example OMEGA2 figure with green arrows showing credit year-to-year carryover that are primarily artifacts of algorithm tolerance, rather than realistic representations of firm compliance strategy.

4. Composite vehicles

***Recommendation 13*:** Alert users in the documentation that the use of composite vehicles can affect choice model predictions in systematic ways that could bias results.

EPA's Response (JM18): Thank you. We will consider adding that to a future documentation release.

Rationale: Providing flexibility to model vehicles at the individual level or at the composite level may be useful. The handling of individual vehicles within the composite is restrictive, but the user appears to have the flexibility to model all vehicles at the individual level if s/he prefers. EPA should be aware, however, that the use of composite vehicles in vehicle choice models has implications for choice model predictions (Yip et al (2018)), and these implications can affect which vehicle solutions are optimal (Yip et al (2021)). Further, while the attributes of individual vehicles can be observed, the attributes of composite vehicles are modeler decisions, and Yip et al (2018) discusses which choices of composite vehicle attributes can produce choice shares equivalent to the shares that would be produced if all individual vehicles were modeled.

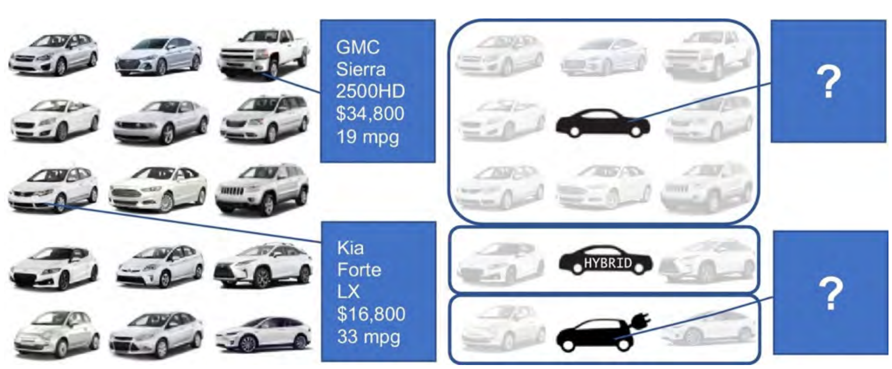

Figure 9: Figure from Yip et al. (2018) showing known attributes of individual vehicles and the question of how to determine attributes of composite vehicles to represent the individuals in choice models.

5. **Exogeneous fuel prices and the rebound effect**

    Recommendation 14: Consider expanding the scope of OMEGA2 to be capable of modeling fuel market rebound for users that wish to model it or, if this is not computationally feasible, include a prominent disclaimer that fuel price endogeneity is structurally excluded and the fuel market rebound effect is ignored in this model.

EPA's Response (JM19): Thank you for the suggestion. We will consider updating that clarification in a future documentation release.

Rationale: Because the policies that users may model with OMEGA2 could have dramatic implications for fuel consumption (e.g.: vehicle electrification), the policies may also substantially affect fuel prices, which will affect fuel use and emissions globally. OMEGA does not allow users to model the effect of policy on fuel prices because they are structurally treated as exogeneous. EPA explained that this is due to computational challenges as well as a belief that fuel price response is likely small. But literature suggests that the "fuel market rebound effect can reduce or reverse climate benefit of low-carbon fuels" (Hill et al. 2016) and the rebound effect is generally non-negligible (Gillingham et al. (2016)), so this effect could potentially be substantial or even dominant, depending on the policies being analyzed.

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4. Mau, P., J. Eyzaguirre, M. Jaccard, C. Collins-Dodd and K. Tiedemann (2008) "The 'neighbor effect': simulating dynamics in consumer preferences for new vehicle technologies," *Ecological Economics* v68 n1-2 p504-516.
5. Shiau, C.S., and J. Michalek (2007) "A game-theoretic approach to finding market equilibria for automotive design under environmental regulation," *Proceedings of the ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Sept 4-7, 2007, Las Vegas, NV, USA.
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7. Yip, A. (2020) *Integrated modelling of consumer choice, producer decisions, and policy design in the automotive market*, PhD. Dissertation, Carnegie Mellon University, Department of Engineering and Public Policy, Pittsburgh, PA.
8. Yip, A., J.J. Michalek and K. Whitefoot (2018) "On the implications of using composite vehicles in choice model prediction," *Transportation Research Part B: Methodological*, v116 p163-188.
9. Yip, A., K. Whitefoot and J.J. Michalek (2021) "Implications of competitor representation for profit-maximizing design," *ASME Journal of Mechanical Design* v144 n1 p011705.

Appendix

Simplified Matlab code demonstrating (1) that minimizing producer generalized cost (including willingness to pay) is not consistent with profit maximization and (2) that constraining average prices to be equal to average prices under fixed margins restricts profitability and changes technology adoption decisions.

```
function run()
  % Reports solution to two problems:
  % 1) minimize average unit producer cost and
  % 2) maximize average unit profit
  % with respect to x = [price1, price2, productioncost1, productioncost2]'
  % for a two-product producer (production cost is a proxy for technology)
  % subject to sales-weighted average price constraints from OMEGA2
  % given a fixed baseline margin m=1.5
  % as well as without sales-weighted average price constraints "Free"
  % with a logit demand function

  % Set up the problem.
  x0 = rand(4,1);        % Random starting point
  LB = [0;0;0.1;0.1];    % Lower bounds
  UB = [inf;inf;1;1];    % Upper bounds
  beta = [1 -2];         % Utility function coefficients for [k;p]
  options = optimoptions('fmincon','MaxFunctionEvaluations',inf,...
    'MaxIter',inf,'Algorithm','sqp','TolX',1e-14,'StepTolerance',1e-14);

  % Minimize production cost w/ constrained prices
  [x,fval,exitflag] = fmincon(@(x)cost(x,beta),x0,[],[],[],[],LB,UB,...
    @(x)nonlcon(x,beta),options);
  MinCost = round([x; q(x,beta); cost(x,beta); gencost(x,beta);...
    -negprofit(x,beta); exitflag],2);

  % Minimize producer generalized cost w/ constrained prices
  [x,fval,exitflag] = fmincon(@(x)gencost(x,beta),x0,[],[],[],[],LB,UB,...
    @(x)nonlcon(x,beta),options);
  MinGenCost = round([x; q(x,beta); cost(x,beta); gencost(x,beta);...
    -negprofit(x,beta); exitflag],2);

  % Maximize profit w/ constrained prices
```

```
  [x,fval,exitflag] = fmincon(@(x)negprofit(x,beta),x0,[],[],[],[],LB,UB,...
    @(x)nonlcon(x,beta),options);
  MaxProfit = round([x; q(x,beta); cost(x,beta); gencost(x,beta);...
    -negprofit(x,beta); exitflag],2);

  % Minimize production cost w/ free prices
  [x,fval,exitflag] = fmincon(@(x)cost(x,beta),x0,[],[],[],[],LB,UB,[],options);
  MinCostFree = round([x; q(x,beta); cost(x,beta); gencost(x,beta);...
    -negprofit(x,beta); exitflag],2);

  % Minimize producer generalized cost w/ free prices
  [x,fval,exitflag] = fmincon(@(x)gencost(x,beta),x0,[],[],[],[],LB,UB,[],options);
  MinGenCostFree = round([x; q(x,beta); cost(x,beta); gencost(x,beta);...
    -negprofit(x,beta); exitflag],2);

  % Maximize profit w/ free prices
  [x,fval,exitflag] = fmincon(@(x)negprofit(x,beta),x0,[],[],[],[],LB,UB,[],options);
  MaxProfitFree = round([x; q(x,beta); cost(x,beta); gencost(x,beta);...
    -negprofit(x,beta); exitflag],2);

  % Report results
  T = table(MinCost,MinGenCost,MaxProfit,MinCostFree,MinGenCostFree,MaxProfitFree,...
    'RowNames',{'price 1','price 2','cost 1','cost 2','demand 1','demand 2',...
    'total cost','gen cost','profit','exitflag'});
  disp(T);
end

%% Average price constraint
function [g,h] = nonlcon(x,beta)
  m = 1.5;       % Fixed baseline markup
  [p,k] = nameVariables(x);

  h = [q(x,beta)'*p - q(x,beta)'*(m*k)];    % Equality constraint
  g = [];                                   % No inequality constraints
end
```

```
%% Demand function
function [demand] = q(x,beta)
   [p,k] = nameVariables(x);
   v = beta(1)*k + beta(2)*p;         % Utility function
   demand = exp(v)/(sum(exp(v))+1);    % Logit demand
end

%% Production cost
function [c] = cost(x,beta)
   [p,k] = nameVariables(x);
   c = q(x,beta)'*k;   % Share-weighted production cost
end

%% Producer generalied cost
function [cG] = gencost(x,beta)
   [p,k] = nameVariables(x);
   WTP = -(beta(1)/beta(2))*(k);
   % Relative WTP based on coefficients of the utility function
   % (note, WTP here is relative to the outside good, which has k=p=0)
   cG = q(x,beta)'*(k - WTP);     % Producer generalized cost using logit WTP
end

%% Profit
function [P] = negprofit(x,beta)
   [p,k] = nameVariables(x);
   P = -q(x,beta)'*(p-k);   % Average unit profit
end

%% Split variables
function [p,k] = nameVariables(x)
   p = x(1:2);           % Prices
   k = x(3:4);           % Production cost
end
```

Sample Results:

	MinCost	MinGenCost	MaxProfit	MinCostFree	MinGenCostFree	MaxProfitFree
price 1	7.35	7.4	1.16	6.94	6.03	0.82
price 2	0.15	0.15	1.03	10.84	7.98	0.82
cost 1	0.46	0.45	0.86	0.1	0.1	0.1
cost 2	0.1	0.1	0.6	0.81	0.57	0.1
demand 1	0	0	0.16	0	0	0.15
demand 2	0.45	0.45	0.16	0	0	0.15
total cost	0.05	0.05	0.23	0	0	0.03
gen cost	0.02	0.02	0.12	0	0	0.02
profit	0.02	0.02	0.12	0	0	0.22
exitflag	1	1	1	1	1	1

Comparing the first three columns, in this example, with this particular logit utility function parameters, the minimum production cost solution and minimum producer generalized cost solution (which includes WTP from the logit model) are nearly identical. Different utility function coefficients ("beta") produce different results, and the minimum production cost solution can differ from the minimum producer generalized cost solution. This example illustrates that including discrete choice model-based WTP in producer generalized cost is not generally consistent with profit maximization. In contrast, including negative total producer *revenue* in producer generalized cost does make it equivalent to profit maximization.

Comparing the first three columns to the last three columns, the optimal solutions when price is treated as a free variable differ from the optimal solutions when share-weighted average price is constrained to match share-weighted average prices under a fixed 1.5 × margin. When prices are not constrained, the cost-minimizing producer sets prices high to generate zero sales. The solution minimizing producer generalized cost is the same in this case, though it can change depending on the utility function coefficients, suggesting again that WTP is not the right way to include revenue in the producer generalized cost function. Finally, the profit maximizing solution with free prices produces higher profit than the profit maximizing solution with average price constraints, suggesting that the average price constraints in OMEGA2 are restricting its ability to model automaker profit maximizing behavior.

5.4 Comments Submitted by Mr. Richard A. Rykowski

5.4.1 General Comments

Re: Comments on OMEGA 2.0

Dear Ms. Waite:

I appreciate the opportunity to comment on the current version of the OMEGA2 model via the peer review process. My comments are attached.

I've tried to organize my comments by topic through the use of headings. I apologize for the wordiness of some of the comments. I concentrated my time on addressing as many aspects of the model as time allowed, and not on producing a tightly worded finished product.

5.4.2 Specific Comments

General Model Design

Output Only Applying to One Case

The absence of figures and tables which compare the results of two or more cases is a significant weakness. Going through the figures provided in the demo batch output, I constantly have to compare two separate figures, except for the one showing total vehicle sales by year. In that case, the figure for the Action case of demo batch a showed the context sales, as well as sales under the Action case. In the analogous figure for the NoAction case, the “three” curves showing context sales, sales under the NoAction policy and consolidated OEM sales all appear to be the same. Thus, I wonder if the figure for the Action case would have showed the results of the NoAction case had these been different than the context sales. Thus, this one figure might not be an exception.

EPA’s ICBT tool was designed to provide comparisons of two regulatory strategies. OMEGA2 already has access to every value of every table output for each regulatory case. It would seem to me very easy to simply perform a comparison of cases which the user requests much as was done by ICBT. The absolute results of any one regulatory scenario are rarely sufficient for any analysis. Thus, OMEGA2’s current output for any single case has limited usefulness on its own (e.g., estimates of technology penetration levels). The issue is almost always how the impacts of one regulatory approach differ from those of another.

> **EPA’s Response (RR01):** The calculation of differences between sessions will typically require that results are aggregated at some level that is of interest to the user, and values weighted according to the number of vehicles in the aggregated group. We cannot anticipate in advance what aggregation will be of most interest to the user (e.g., aggregation by various combinations of regulatory class, body style, manufacturer, fuel type, etc). Instead, the model outputs, comprised of absolute values, have been organized in a format to facilitate pivot tables and pivot charts that can flexibly provide deltas.

Odd Results

From the 2021_11_17_11_31_31_demo_batch-context_a_NoActionPolicy V Cost Mkt Cls.png figure, I see that the cost of both hauling and non-hauling ICEVs decreases substantially over time, except for the bump in hauling ICEV cost when upstream emissions begin to be included in BEV certification. I understand the effect of learning on GHG control technology. However, the decrease in hauling ICEV cost between 2020 and 2034 is more than $2000 per vehicle. This is likely greater than the cost of the GHG technology on the vehicle in 2034, so it can’t be due to learning. The cause of this decrease should be noted and explained.

> **EPA’s Response (RR02):** The demo example included with the peer review package was intended for illustrative purposes only and was not meant to represent actual vehicle technology costs. The user can specify technology costs in the model inputs.

Tracking of Producer GHG Credits

I understand that the treatment of GHG credits is not yet complete in the version of OMEGA2 that I reviewed. However, I have a comment on this topic that is likely to carryover to future versions of the model which I believe could benefit from modification.

OMEGA2 currently only calculates a producer’s total GHG credits generated or used each model year. The rationale is the unlimited level of credits which can be traded between passenger car credits and light truck credits.

These credits are indeed fungible. As OMEGA2 currently does not consider the use of banked credits in facilitating compliance to the degree reflected in the real world, the issue is moot. However, should EPA develop methods in OMEGA to allow its simulations of producer responses to GHG regulations to include the use of banked or purchased credits, it is paramount that OMEGA2 track GHG credits from passenger cars and light trucks separately.

The reason is that credits can generally only be carried forward a fixed number of years. A producer of both cars and trucks can generate positive car credits and negative truck credits, for example, in the same year. This producer does not need to use its current car credits to mitigate or resolve its current negative truck credits. It can use its previously banked credits to resolve its negative truck credit balance and bank its current car credits. This effectively extends the life of a portion of its credit bank. OMEGA2's current approach negates this possibility, which is explicitly allowed and even encouraged by EPA's current GHG regulations. OMEGA2 calculates car credits and truck credits separately internally. Thus, I see no reason why OMEGA2 could not simply output each credit balance separately, as well as a combined balance. Until EPA adds a methodology for the use of banked credits, compliance in the current model year could still assume the immediate use of current car or truck credits to compensate for a negative credit level from the other vehicle class. But at least the model would be set up for the eventual more realistic modeling of banked credit use and credit trading in the future.

> **EPA's Response (RR03):** Thank you for the suggestion. The latest version of the model incorporates credit banking. Please see the response to comment JG13. New output files track credit balances and credit transactions from year to year, by manufacturer. The model does not apply any restrictions that distinguish between car and truck credits for averaging, banking, or trading. Therefore, the credit output files do not report credits by regulatory class. However, that information can be aggregated by the user from the detailed vehicle outputs.

Use of GHG Credits

I make two simple suggestions for simulating the use of credits in OMEGA2 as EPA develops methods to do so in the future. First, if the model finds that credits are expiring unused, it repeats its analysis of the past 5 years and allocates the credits that would have expired evenly over each of the 5 years. This is clearly simplistic, but clearly better than letting credits expire. Spreading their use out over 5 years also maintains a gradual increase in the application of technology and avoids situations where the model might be tempted to reduce the application of technology, which, while possible in certain cases, is generally problematic from a regulatory point of view.

> **EPA's Response (RR04):** Thank you for the recommendation. In implementing the credit banking logic, banked credits from the base year inputs (historical credits) are used to reduce the compliance burden in the early analysis years, up until the most recent credits expire. Credits earned during the analysis years are used only to fill compliance gaps, if any, and are not used to strategically under-comply. Debits accrued during analysis years are paid off, if necessary, by subsequent strategic overcompliance, with the amount of overcompliance increasing over time if it takes more than one analysis year to repay the debit. The strategic use of credits is an open area of study, and many compliance strategies are possible. In general, we don't observe that the use of credits greatly affects the cost of compliance, so we have implemented a rather straightforward strategy that has effects that are easily explained and understood.

When OMEGA2 finds a situation where compliance is not possible, I again suggest that the model repeat its analysis of the previous 5 years increasing the stringency of the GHG standard by one fifth of the level of non-compliance. If the model cannot converge at these more stringent standards, at least some level of credits would hopefully be generated. If fewer than all of the five years are unable to reach these tighter standards, OMEGA2 could push further in the years which were able to comply to determine if even more stringent standards were feasible and could generate the needed credits.

> **EPA's Response (RR05):** Thank you for the suggestion. While the latest version of the model does incorporate the use of historical banked credits, it does not have the capability to strategically over comply in earlier years in order to deliberately build a credit bank for later compliance, or to minimize overall costs. Credits earned through voluntary overcompliance, however, can be used in later years to make up a compliance shortfall, as the reviewer recommends. We will consider the possibility of implementing strategic over/under compliance over a multi-year time horizon in a future version of the model.

Context

Fuel Costs (p. 41 User Guide, Section 4.1.4)

Fuel costs in OMEGA2 are part of the "context" and are assumed to be unchanged. Analyses utilizing EIA's NEMS modeling system have shown that changes to CAFE standards (and thus, GHG standards) have a significant impact on gasoline price.[1] EPA has traditionally taken its projections of future gasoline from EIA analyses based on NEMS. Thus, it is actually inconsistent to not use this same model for the impact of gasoline demand on gasoline price. The relative impact of CAFE and GHG standards on U.S. gasoline demand generally far exceeds their impact on vehicle prices in percentage terms. I strongly recommend that EPA add the capability to account for the impact of GHG standards on the price of gasoline to OMEGA2.

A question was posed on this topic by one of the peer reviewers: "Exogenous Fuel Prices: Is it necessary in the model structure to assume that fuel prices are not affected by (potentially large) changes in fuel consumption?"

EPA's Response was: "Given our current understanding of the relatively small magnitude of a fuel price response, we are not currently planning to pursue an investigation or adoption of endogenously modeling fuel prices. The challenge with endogenously modeling fuel prices is that it requires an additional feedback loop where consumer and producer decisions influence fuel prices, which in turn influence consumer and producer decisions. While that approach is technically feasible, it is also more difficult to model and has possible tradeoffs with run time and tractability. If you are aware of any evidence that the fuel price response would be significant enough to merit further consideration within the model, please feel free to elaborate in your review."

I believe that I have done that. The change in gasoline prices found using NEMS was very significant in my view.

> **EPA's Response (RR06):** Thank you for the suggestion. This version of the model does not include an endogenous fuel price response. We will consider adding that capability in a future version of the model.

Rebound Rate

The current version of OMEGA2 only allows the specification of a single rebound rate. I suggest that EPA add the capability to specify two rebound rates. One would apply to fossil-fueled vehicles. the other would apply to battery electric vehicles for two reasons. One, fuel cost per mile for battery electric vehicles will be much lower than those for fossil-fueled vehicles. This will produce significant increases in electric vehicle miles

1 One of several potential references on this issue: Petition for Reconsideration of EPA's Final Rule—The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, Docket No. EPA-HQ-OAR-2018-0283, June 29, 2020

relative to fossil fueled vehicles. Two, electric vehicles face challenges for fast recharging that fossil fueled vehicles do not.

> **EPA's Response (RR07):** Thank you for the suggestion. We have implemented the capability for the user to assign separate rebound rates for BEV and ICE vehicles.

Price Multipliers

The current version of OMEGA2 only allows the specification of a single technology price multiplier. Past EPA analyses (TAR) utilized indirect cost multipliers which varied by the type of technology being addressed. I suggest that EPA address this issue in the User's Guide. Indirect cost multipliers could be embedded in the total technology package costs input via the vehicle_simulation file and the price multiplier set to 1.0. This possibility could be discussed in the User's Guide.

> **EPA's Response (RR08):** Thank you for the suggestion. In the current version of the model, the user can specify different markups by powertrain type in the input files.

Producer Module (Section 4.3)

Description of the Cost and Effectiveness of GHG Control Technology: Vehicle_simulation file

The estimates of the cost and effectiveness of GHG control technology in OMEGA2 are contained in the vehicle_simulation file. The vehicle types addressed in the demo file line up with the very basic vehicle types used in much of the technology effectiveness calculations made on the Effectiveness worksheet of the Machine from the OMEGA1 process. I assume that these 6 vehicle types were chosen because they represent the majority of the very specific vehicle simulation results produced using ALPHA. What seems to be missing is a more specific application of these general projections to individual vehicles, which was also performed by the Machine.

EPA seems to be emphasizing the description of GHG control effectiveness through the use of absolute CO2e emission levels. However, individual vehicles (thousands, not the 51 included in the demo vehicles file) vary by their absolute emission level. I see vehicle characteristics which could be used to modify both the relative and absolute effectiveness of GHG control technology in the vehicles file. However, I did not see any reference to the use of these attributes to do so. This seems to be a fundamental requirement in the projection of adding control technology to the baseline fleet or determining the technology required to enable compliance. Using the absolute GHG emissions for six vehicles seems to be a very crude method to reflect the baseline emissions of the fleet. It is not clear from the discussion of the Producer module in the User's Guide whether the baseline emissions listed in the vehicles file are used to adjust the emission levels of the exemplar vehicles listed in the vehicle_simulation file or not. As discussed further below, it appears that these emission levels from the vehicles file are not being used, at least in the generation of cost clouds and cost curves. I see this as a fundamental issue with projecting future producer compliance with GHG standards.

In a response to a question in this area, EPA stated: "EPA recommends the generation of RSEs (response surface equations) to derive particular cost clouds unique to each vehicle."

It is not clear to me whether these RSEs describe GHG performance, technology cost, or both. Nor was it clear whether these RSEs would replace the extensive lists of technologies in the vehicle_simulation file or would be used to adjust the effectiveness of these technologies for the individual vehicles listed in the vehicles file. I recommend the latter.

Considering both the cost and effectiveness of GHG control technology, EPA seems to be assuming that the approach to accurately estimating the GHG effectiveness of technology needs to be the same as that used to accurately estimate the cost of this technology. I do not believe that this is true. The interactions of technology on GHG performance are very complex and overlapping. Two plus two in this space does not equal four. That is the reason EPA developed the very sophisticated, ALPHA model. Synergies and dis-synergies dominate this task. This is also why EPA lists about 100,000 technology packages in the vehicle_simulation file in the demo package for each of six very basic vehicle types.

The costing of technology is also very complex, but at a completely different level. The complexity of technology costing is developing an accurate estimate of the cost of a single technology (e.g., accounting for the cost of the added and subtracted parts, the cost of modifications to existing parts, the difference in the cost of assembling these different sets of parts, even changes to warranty costs, etc.). Usually, there is no synergy or dis-synergy is the costing of two technologies (e.g., gasoline direct injection and an 8-speed automatic transmission). When there are, such as the costing of hybrid or battery electric powertrains with various degrees of mass reduction, these can be addressed through a thorough accounting of how the cost of the one technology is affected by the other. In this example, the lighter the vehicle, the lower the cost of hybridization. Equations or RSEs can be easily developed to describe these limited interactions. (See the OMEGA_TechCosts files.)

Thus, while EPA's vehicle_simulation file lists 100,000 distinct technology packages for each of six ICEV classes, EPA's OMEGA_TechCost file for OMEGA1 is able to provide achieve greater precision in the costing of technology packages using a total of less than 12,000 lines for the entire vehicle fleet. By providing the cost and GHG performance of technology to OMEGA2 in exactly the same way, EPA has forced a compromise where one is not needed, in this case, technology costs.

The synergies or dis-synergies involved in GHG performance require the separate treatment of enormous numbers of technology packages. At the same time, the adjustment of these final CO2e emission levels to represent individual vehicles which only differ by starting emission level, total mass or aerodynamic drag is fairly straightforward and could be accomplished using information already being provided via the vehicles file. This does not appear that this is being done, since neither the vehicle_simulation file nor the vehicles file provide coefficients which would describe such adjustments. EPA's emphasis on the desirability to describe GHG performance in terms of absolute CO2 emissions seems to confirm this, since any such adjustments would require converting these absolute emission levels into percentage changes. Also, when discussing Figure 4-9, EPA states that the minimum cost curves for several individual vehicles overlap. The wide variability in the vehicles described in this figure indicates that EPA is applying the absolute CO2 emissions described in the vehicle_simulation file to individual vehicles and no adjustment is being made. If correct, this introduces significant errors in the results.

When I raised this question to EPA staff, they responded: "The reviewer is also observing that the technology present on an existing base year vehicle is not considered when the Producer module considers the design of a vehicle in the future. This is true in the demo example. It might be helpful to consider the producer decision in OMEGA2 as follows: In a future year, "*how should a vehicle be designed which has certain characteristics (utility, size, performance) using available technology packages?*" Note that this is a different framing of the question than is posed in OMEGA1, which could be described as "*how should the technology components of an existing vehicle be modified without changing characteristics of utility, size, performance?*" We think that the advantages of how we are framing the question in OMEGA2 include 1) it ties emissions rates more closely with the simulation results (mentioned above), 2) it eliminates the high model sensitivity of assigning discrete technologies manually to the historical fleet (mentioned above), and 3) it enables the model to consider producer changes in vehicle attributes as a policy response. We acknowledge that while there are benefits to our OMEGA2 approach, it requires additional effort in ensuring that ALPHA results reliably represent absolute emissions levels as a function of vehicle loads, performance capabilities, and technology applications."

I think that regardless of which question is being asked, the answer must eventually converted into an impact on vehicle cost. This can only be done accurately if one knows the starting point. In all past regulatory analyses, EPA has used the cost of a vehicle fleet from some recent model year. These vehicle designs are not consistent with the most basic vehicle uses in describing its ALPHA-based emission values and technology costs listed in the vehicle_simulation file. Actual vehicle fleets display much greater variability. Some of this variability is reflected in the six vehicle types used in the vehicle_simulation file, but the granularity there is sorely lacking.

The approach taken in OMEGA1 basically starts with this highly varied actual vehicle fleet and adds technology which is cost effective from EPA's point of view. This retains most of the variability in vehicle design reflected in the baseline fleet and recognizes the cost of the solutions which producers have already implemented. EPA may be shifting to a different approach where it projects the design of a vehicle fleet which meets the No Action policy as well as the Action policy. While this affects the inputs to OMEGA2, which is not a part of this peer review, I believe that the current design of the Producer would make it very difficult for a user to incorporate the type of regulatory analysis which has traditionally been conducted by both EPA and NHTSA. Given the amount of effort required to develop a baseline fleet at the level of detail used by EPA and NHTSA in the past, it may be unlikely that an entity or individual would develop one on their own. The one exception could be one or more producers desiring to demonstrate the effect of this dramatic change in baseline fleet design on projected costs of compliance. If the direct use of a very simplified baseline fleet is EPA's intent, I suggest that it be made explicit in the User's Guide and used as a reason for describing the effectiveness and cost of technology packages in exactly the same way.

> **EPA's Response (RR09):** This comment appears to be specific to the demo example provided as part of the peer review package. The level of resolution of the base year fleet can be specified by the user in defining the model inputs. It was not our intention to restrict the model to only a simplified base year fleet.

Separate Treatment of Hybrid Technology

In the demo, EPA generally lumps vehicles into hauling and non-hauling categories and into ICE and BE categories. However, the demo OMEGA runs included in the review package designate some ICEVs as HEVs.

For example, the vehicle_simulation file includes a set of ~20,000 technology packages for six basic HEV types. HEV as also a designator for some of the vehicles in the vehicles file. HEV is the only technology shown in the vehicles file which does not place the vehicle into a car/truck class or ICEV/BEV class.[2] For example, Figure 4-9 shows a least generalized cost curve for a hybrid, subcompact vehicle. OMEGA2 seems to be treating hybridization as an ICE technology in a unique way by only applying technology packages to hybrids which include hybridization when it develops the cost cloud for full hybrid vehicles. This seems to run counter to EPA's express desire to avoid manually describing the technology present in the baseline fleet.

This unique treatment of hybrids is not discussed in the User's guide. While this is a significant improvement over ignoring the cost and effectiveness of hybridization already present in the baseline fleet, it serves as an example of the compromise being made with regard to non-hybrid ICE technology present in the baseline fleet. EPA appears to be ignoring the fact that significant swathes of the current fleet already reflect advanced engines, advanced transmissions, etc. It is also not clear how the Producer module considers the HEV packages listed in the vehicle_simulation file when treating non-hybrid ICEVs. Presumably, it considers the application of both non-hybrid and hybrid packages. But how the model knows to do this is unclear.

2 Fuel cell technology is also listed, but there are no FCEVs listed in the demo vehicles file and it doesn't appear that any fuel cell technology packages are listed in the vehicle_simulation file.

As an aside, ICCT has shown that mild hybridization coupled with advanced engine technology can achieve GHG performance comparable to full hybrids at much lower cost.[3] These vehicles would apparently be treated as non-hybrid vehicles in OMEGA2. This approach would likely be fine for non-hybrid vehicles in the baseline fleet. Even if advanced mild hybrid packages reached the effectiveness of full hybrid packages, their lower cost would lead to them being selected prior to full hybrid packages in EPA's cost cloud. If full hybrid packages were slightly more effective, they would still appear at the left side of the cloud as the slope of the least-cost line would become very steep at this point (large increase in generalized cost for a very small reduction in GHG emissions. However, this would not account for the possible conversion of current hybrids to mild hybrid designs with considerable cost savings in the future.

Conceptually, EPA's special treatment of hybridization as an ICEV technology could be extended to other technologies. However, extending this "path" approach has been shown to be problematic in numerous comments made to NHTSA GHG rules. EPA's approach of comparing all of the available ICEV packages at the same time is preferable. The problem is the consolidation of the baseline fleet, not in the evaluation of the best technology packages for a selected group of vehicles.

That said, in OMEGA1, EPA developed least-cost paths for roughly 40 vehicle types versus the six used in the GHG effectiveness modeling and the six to twelve used in the demo package for OMEGA2. Time did not allow me to compare the least-cost paths for these 40 vehicle types to determine is groups of them were very similar with similar effectiveness. If the paths for vehicles types falling into the six basic vehicle types all had the same least-cost path, then evaluating only these six would be satisfactory. If they did not, I suggest that EPA consider a slightly expanded set of vehicle groups evaluated in the vehicle_simulation file. (This last comment could be considered to be a comment on an input file and not on the OMEGA2 model itself.)

> **EPA's Response (RR10):** In the latest version of the model, we have implemented the capability for response surface representations of the available technology packages to be assigned to specific vehicles in the base year fleet. The user can define inputs for response surfaces for any number of technology packages, including differentiating between hybrid and non-hybrid packages, and various types of hybrid technologies.

Vehicle Cost Clouds and Curves

Figure 4-7 shows a cloud of vehicle cost versus CO2 emissions and generalized cost versus emissions for a single vehicle, #62. I could not find a vehicle #62 in any of the input files. Nor could I find a vehicle which matched the group of descriptors for #62 (ICE Large Van truck minivan 4WD).[4] Therefore, I could not tie back either the cost or emission values shown in the figure to any of those in the input files. Specifically, I could not determine if the starting emission level shown in Figure 4-7 (the rightmost point in the cloud) came from the vehicle_simulation file or the vehicles file. The former contains base emission values for roughly 18 vehicles, while the latter contains base emission values for 51 vehicles, reflecting more vehicle specificity.

This ties back to my earlier comment that the base emission level for the individual vehicle being evaluated should be based on the actual base emission level of an actual vehicle, or at minimum a group of vehicles

3 White Paper, EFFICIENCY TECHNOLOGY AND COST ASSESSMENT FOR U.S. 2025–2030 LIGHT-DUTY VEHICLES, Nic Lutsey, Dan Meszler, Aaron Isenstadt, John German, Josh Miller, ICCT, March 2017

4 I was unable to find this vehicle in the "vehicle.csv", "simulated_vehicles.csv" or "context_new_vehicle_market.csv" files. While I was able to find three "Large Vans" in the context_size_class column of the vehicle.csv file, the other descriptors of these vehicles did not include truck minivan 4wd. All three Large Vans fell into the cost class, ice_MPW_HRL. I found 98,952 lines of data referring to ICE_MPW_HRL in the simulated_ vehicles.csv file. I presume that each line describes a technology package. I found twenty technology packages for this vehicle class which showed "0" in all the technology tracking columns. Of this list package ICE1027 appears to be the baseline vehicle, as it shows the lowest vehicle cost, though it is listed second in the list (package ICE1025 is shown first).

which shared the same platform (e.g., engine type and no. of cylinders, transmission type and no. of gears, degree of hybridization, etc.). Also, the rightmost emission value should reflect the technology package present on the vehicle, as OMEGA2 should not be adding technology which is already present in the fleet.

EPA does not describe the procedure used to generate the least cost curve. EPA does refer to it as defining the “frontier” of the cloud and that OMEGA2 automatically generates it. The location of the least-cost curve vis-à-vis the cloud implies that the method EPA has programed into OMEGA2 applies the same or very similar logic to that used in the Tech_Ranking_Generator which was constituted a step in the OMEGA1 process. If so, I would commend EPA’s approach. If not, it would be helpful to know what logic is used.

> **EPA’s Response (RR11):** In the latest version of the model, with the implementation of redesign cycle constraints, base year vehicle emissions levels are carried forward until the first redesign opportunity. Base year vehicles are aggregated into shared platforms according to powertrain and driveline type, manufacturer, size class, etc. We have implemented response surface equations which represent absolute vehicle emissions and complete technology packages. As a result, at each redesign opportunity there is no risk of adding an individual technology to a vehicle that already has it.The cloud of points is now generated internally to the model, as is the associated cost curve ‘frontier’. We will consider providing an enhanced description of the cost cloud and cost curve generation approach in a future version of the model documentation.

EPA also does not discuss the situation where the user might desire to restrict the application of a technology to less than 100% of a vehicle’s sales. The ranking process used in OMEGA1 allowed this. I recommend that this capability be available in OMEGA2 and discussed. I see some input files with references to BEV penetrations, but none which refer to specific technologies. The use of limits should be discussed in the User’s Guide.

One important issue is whether this sales penetration cap apply at the vehicle level or to some group of vehicles, which could even be industry wide. This should be considered, as well.

> **EPA’s Response (RR12):** The reviewer is referring to the application of technology penetration caps in the previous version of OMEGA, which could restrict the share of specific technology applications. Now that the modeling incorporates constraints on redesign cycles, BEV ramp rates, and battery production constraints, we do not think that there is a justification or need for additional technology-specific constraints.

OMEGA2 then aggregates the least-cost curves for all(?) of the vehicles which fall into a sub-grouping whose relative sales mix is not affected by the Consumer module. This allows this cost curve to be used throughout a set of iterations between the Producer and Consumer modules. Further, as one of common uses of OMEGA2 will be to evaluate a set of GHG emission control options with no changes to the vehicle fleet or technology availability, this same cost curve could be used across the set of OMEGA2 runs. I recommend that EPA install an option (controlled through the GUI) which would generate the lowest generalized cost versus GHG emission relationship for each such vehicle grouping and save the results in the input folder. The user can then refer to this file for any OMEGA analyses which utilize the same vehicle fleet and set of available technologies. These subsequent analyses can vary the type and stringency of GHG controls and vary consumer response to vehicle prices, as long as these responses to not affect any vehicle types which were originally “grouped” in the development of the least generalized cost versus GHG emission curves. This will clearly reduce processing time or allow a much more detailed evaluation of technology cost and effectiveness on baseline vehicles with no increase in processing time.

> **EPA’s Response (RR13):** Thank you for the suggestion. We are interested in finding ways to improve the computational efficiency of each OMEGA run, and re-using common inputs is a reasonable strategy.

> There are a couple of additional consideration for the most recent version of the model that would complicate the re-use of cost curves across policy sessions. The first is that redesign constraints will impact how producer decisions in earlier years might affect the cost curves in later years. If the use of redesign cycles causes differences in cost curves between policy sessions (due to a different prior application of technology) then it may be difficult to re-use cost curves across policy sessions. Second, the model allows the user to specify different cost inputs between sessions, which would result in different cost curves. We will continue to consider other ideas for improving computational efficiency for a future version of the model.

Returning to the aggregation process, EPA does not describe the methodology used to aggregate the least-cost curves for each discrete vehicle. EPA does state that the "… processes of vehicle aggregation (also referred to as composition or the creation of "composite vehicles") and decomposition are critical for the solution search process. First, aggregation allows the model to efficiently search for a solution without a complete enumeration of all possible choice combinations. Second, decomposition allows the model to draw upon the key vehicle attribute details that have been retained and are required for calculating the compliance emissions values and estimating the consumer response."

This aggregation process must use a methodology that maintains the minimization of generalized cost to achieve a specified GHG standard. One, this requires sales-weighting. The individual least cost curves could actually be sales-weighted prior to combination. Two, this requires evaluation of the slope of line segments constituting each least cost curve (classic calculus). These line segments can then be ranked according to their slopes, starting with the one with the most negative slope and moving upwards from there. This is the process used in OMEGA1 to select the order in which to apply technology across all of a manufacturer's vehicles. I believe that this would be consistent with everything else said in the User's Guide. It is also very easy to accomplish mathematically. The curves shown in Figure 4.9 do not reflect this approach for several reasons.[5] However, the figure might be figurative and not indicative of the way that OMEGA2 combines the individual cost curves.

EPA's response to a question about the decomposition of the selected point off of the composite curve shown Figure 4.9 indicates that it is not following the approach described above. EPA refers to the selected point being between two points on the composite curve, which is then connected to points on each individual curve which are also being these two points. This leads me to believe that EPA is combining the individual curves by sales weighting the rightmost and leftmost points (and those in between?). This approaches loses all of the value contained in each individual curve and will not lead to a true least cost solution.

EPA also refers above to a decomposition process which "… allows the model to draw upon the key vehicle attribute details that have been retained and are required for calculating the compliance emissions values and estimating the consumer response." If the line segments of the cost curves are ranked by their slope, as recommended above, the exact technology packages and the resultant GHG emissions, fuel consumption per mile, etc. for specific vehicles can be easily be determined at any point in the process.

However, as neither the aggregation nor decomposition process were described, I can't be sure of the accuracy of the following claim made on page 56: "Because the composite vehicle is made up of individual

5 The greatest reason is the location and shape of the hybrid vehicle curve. It starts at a low emission rate, which is consistent with hybridization. However, it also shows the potential for a 100 g/mi CO_2 reduction with consistently negative generalized cost, which is should not be feasible for a hybrid. I also note that the curve for the Large Utility ICE-HEV does not appear in the figure. This must be because it overlays one of the curves which is shown. Either the emissions and generalized costs for this hybrid are the same as those for non-hybrids, or they are the same as those for a subcompact ICE-HEV. Neither of which is accurate.

vehicles of fixed sales shares (at least relative to the other vehicles in the same market class, reg class combination), there is one-and only-one solution for individual vehicle costs and emissions rates that will result in the selected option for the composite vehicle's cost and emissions rate." Anytime one is combining values off of several "curves", regardless of whether the curves are combined using fixed weighting factors or not, one can easily move "up" one curve and down another at will and still maintain the same average cost. For the statement on page 56 to be correct, there must have been a specific procedure for producing and decomposing the aggregate curves which could only lead to one decomposed solution. I recommend that it be the process that I suggest above.

As an aside, EPA further states that: "Because a producer can offer a range of different vehicles, each with distinct costs associated with applying technology packages, it is not likely that the lowest cost compliance solution will be a uniform application of technology to all vehicles. Nor will selecting the lowest cost option for each vehicle likely result in producer compliance, except in cases where a policy is non-binding." This sounds like OMEGA2 adds technology with a negative generalized cost slope whether or not the GHG standard requires it. If this is true, I suggest that EPA make this clear and refer to the study that demonstrates that producers have actually done so within a short time of a new technology coming to market.

> **EPA's Response (RR14):** To the first point, the model retains all the information associated with each point throughout the composition and decomposition processes. So, there is no ambiguity about how to arrive at a given point on the cost curve.
>
> To the second point, yes, we have added a feature (producer_voluntary_overcompliance) in the latest version of the model does allow the producer to over comply with GHG standards, as long as that approach reduces the producer's generalized cost. To provide a hypothetical example, if emissions reducing technology were projected to become less costly than the incumbent (e.g., BEVs less costly than ICE) and/or the fuel costs assumed to be considered in the producer decisions are sufficiently different, a producer would reasonably expect to apply those technologies, even if it results in overcompliance with the GHG standards. The actual result of overcompliance will be dependent about the user's inputs for, e.g., technology costs, GHG standard stringency, fuel costs considered, etc.

Description of the Baseline Fleet

[There is some overlap between this comment and those made on the cost clouds and cost curves.]

In EPA's response to a question about the very simple description of the baseline fleet in the demo vehicles file, EPA mentions a desire to avoid the burden of manually identifying the discrete GHG control technology already present in the historical fleet. I acknowledge that this is a burden. I also acknowledge that the classification of specific technology being applied by a manufacturer is sometimes difficult and subjective. Still, the degree of this burden does not change the importance of accurately estimating the cost and effectiveness of GHG control technology already being deployed in the baseline fleet. Take a crude example where a producer's vehicles are 100% turbocharged. Converting these vehicles to any lower GHG technology that doesn't involve turbocharging will reduce the cost of this technology relative to converting a non-turbocharged vehicle. Without a precise accounting of this fact, any projections made regarding the potential and cost of additional GHG control would appear to have limited usefulness.

The baseline emissions resulting from the application of specific technology already on the vehicle are also very important. Some manufacturers produce vehicles with greater mass per footprint and higher horsepower per the higher mass than others. They may be employing relatively advanced technology, yet achieving average GHG performance. Of course, this manufacturer can choose to reduce the mass per footprint or power per mass, but the need to do this is only discovered by identifying the GHG emissions of these vehicles after the incremental application of technology.

An EPA response to a question from the peer review group distinguishes between the fundamental questions being asked in OMEGA1 and OMEGA2 when reducing GHG emissions. The question being asked in OMEGA1 was: "how should the technology components of an existing vehicle be modified without changing characteristics of utility, size, performance?". The question being asked in OMEGA2 is: "how should a vehicle be designed which has certain characteristics (utility, size, performance) using available technology packages?"

Per my understanding of the OMEGA1 process, both questions were asked and answered when developing the sequence of technology additions described in the market and technology files. The second question, which EPA says guides the OMEGA2 approach, was addressed in OMEGA1 through the process of identifying the technology packages available for each vehicle type and then evaluating the cost and efficiency of each package. Aspects of the baseline vehicles were only retained if they were part of more effective technology packages not yet applied. In the case of very stringent GHG standards, the final technology projections were very similar to those identified in the least-cost process.

Taken in the extreme, the answer to the OMEGA2 question applies to both the baseline and policy action fleet. In other words, the evaluation of a policy scenario would be done using two idealized fleets. There are rationales for this approach. However, they differ so significantly from previous EPA analyses that I believe they need to be explicitly presented in the User's Guide. If this is not EPA's intent, I suggest that changes be made to the emission and cost estimation processes discussed above.

Finally, all of this is not to say that the relative value of each of the attributes of the baseline fleet have the same value. Differences in engine design are probably very important. Degrees of aerodynamic drag reduction can be significant, but probably less important than engine design. Numbers of gear in transmissions should be relatively easy to quantify. Thus, judgment can inform this develop of a baseline fleet. But some consideration of what has already been done seems very important.

> **EPA's Response (RR15):** Thank you for the suggestion. As described in our response to RR11, the response surface equations provide absolute emissions rates, so there is no risk of adding incremental technologies to vehicles that already have that technology present.
>
> In the most recent version of the model, we have implemented redesign cycle constraints, which involves the assignment of technologies to individual vehicles in the base year. As a result, the level of potential emissions reductions and associated cost will be dependent on the technologies assigned to a base year vehicle. The format for representing technology packages, and the associated emissions rates, is by continuous response surfaces. I.e., each distinct technology package has its own response surface. This approach also allows the model to distinguish between various performance characteristics and other vehicle attributes in the base year (e.g., aerodynamics, power-to-weight ratio, mass) and to maintain or modify those attributes in future years.

Vehicle Redesign Cycles

I see no mention of vehicle redesign cycles in the description of the producer module. I do not recommend the approach taken in the Volpe CAFE model to predict each vehicle's redesign year and then extend these changes to other vehicles whose design may depend on the initial vehicle's redesign, at least not without careful study that demonstrates that producers consistently follow this approach. Vehicle redesign is also much too fluid and within a producer's control for such predictions to be accurate at the vehicle model level.

At the same time, producers cannot redesign all of their vehicles to a significant degree in a single model year. With OMEGA1, the average vehicle redesign cycle was typically assumed to be 5-6 years, implying that 16-20% of a producer's vehicles could be redesigned each year. Modeling the impact of a more stringent GHG standard at least 5 years out was a general requirement if all of a producer's vehicles were allowed to receive significant technology improvements, such as a major new engine or hybridization. The user should be warned of this requirement, since OMEGA2 projects costs one model year after the year of the baseline fleet. This first year of projection may actually be the current year of production or in the past due to the fact that the baseline fleet almost always represents an historical fleet. This presumes the use of a detailed baseline fleet, which may not be EPA's approach with OMEGA2, as discussed elsewhere.

I noticed that the production_constraints-cntxt_a input file contains minimum and maximum levels for BEVs, which is not really a technology in OMEGA2. Do these limits apply to each producer, to the fleet, to an individual vehicle listed in the vehicles file and produced by an individual manufacturer? Is there a way to limit the application of technology in the current OMEGA2 model? I suggest that EPA consider ways to limit major changes in technology across a manufacturer's fleet in the first few years of a run.

> **EPA's Response (RR16):** In the most recent version of the model, we have implemented several changes that are relevant to the reviewers' suggestions. First, the user can choose to specify an initial analysis year that is not the year immediately following the base year used to describe existing vehicles and their attributes. The model will carry forward those base year vehicle attributes as unchanged until the first analysis year. Historical banked credits, for which data may be more recent than the base year vehicles, would be provided up until the year prior to the first analysis year. (for example, MY2019 base year would carry forward vehicle attributes unchanged to MY2021, with a MY2022 initial analysis year).
>
> Second, we have implemented redesign constraints, for individual vehicles with greater detail about the applied technology packages in the base year as described in our response to comment JG19. Also, we have implemented a ramp rate limit, which provides in upper bound on the portion of a base year vehicle model's production that can be converted between ICE and BEV powertrains.

Fleetwide Vehicle Sales in the First Iteration of the Producer Module Following Year One

The starting point of vehicle sales by vehicle segment in each successive model year being evaluated during an OMEGA2 run was not clear to me. On the one hand, it could be the vehicle sales reflected in the context_new_vehicle_market.csv file. Or it could be the sales for each vehicle segment settled upon for the previous model year. Both have value. One potential problem with using the level of vehicle sales in the context file is that the assumptions made by whatever entity which made the projections may differ and overlap with those implicit in the OMEGA2 run. For example, if future sales were taken from an Annual Energy Outlook projection, that projection would necessarily include some projection of CAFE standards into the future, as well as technology costs. Either sets of inputs will likely differ from those being modeled using OMEGA2.

I lack the expertise to know if the converged levels of various market segment sales depend on the starting sales levels going into the convergence process. If they do (for the types of consumer preference relationships being envisioned), this is a significant problem. If they do not, then it is only a matter of computing time. Given the likely divergence between assumptions involved in projecting the levels of vehicle sales reflected in the context file and those being modeled in OMEGA2, it would seem reasonable to use those in the context file for a couple of model years and then begin using the sales projected in OMEGA2 for the previous model year. For example, an OMEGA2 run projecting the cost of increasing stringent GHG standards could be expected to require significant levels of vehicle electrification (e.g., BEVs). The source of future vehicle sales reflected in the context file may have assumed no increase in the stringency of GHG standards and thus, reflect very low levels of vehicle electrification. It wouldn't make much sense to project 10% BEV sales in the previous model year and start out the next model year with 2% BEVs.

> **EPA's Response (RR17):** The model is designed to use an external sales projection, which is associated with its own assumptions about the policy. This is called the "analysis context", and the user is required

to set up the policy definition in the first session of a batch to match the policy definition in the external sales projection. The model will then automatically calibrate the sales output from that session to match the external projection. And subsequent policy sessions within the same batch will estimate the vehicle price and fuel consumption changes, and the resulting sales changes, relative to the first session. For example, if an AEO 2021 projection is used for the analysis context, then the first session of the batch file should be set up to use the 2020 FRM for light-duty GHG standards, and no IRA provisions, consistent with the assumptions used in AEO 2021.

Consumer Module (Section 4.4)

Modeling Consumer Preferences for BEVs

The demo package includes six BEV models, which vary by size class and car-truck class. Realistic projections of BEV penetration will likely involve BEVs which differ by range, as well. The current framework for including BEVs in both the Producer and Consumer modules appear to be sufficiently flexible to handle treatment of BEVs of differing range. If not, I suggest that EPA consider this likely need and modify OMEGA2 to be able to address it.

EPA's Response (RR18): Thank you for the suggestion. The model can accommodate different BEV ranges with the definition of separate market categories. For example, 200 mile and 400 mile range BEV categories. The user would need to establish the appropriate sales share response inputs to capture any differences in consumer acceptance between the two ranges.

Future Vehicle Sales by Market Share

EPA's response to a question posed to the staff clarified my understanding of the way that OMEGA2 adjusts individual producer sales to conform with future fleetwide sales and market class sales. The spreadsheet which EPA provided[6] helped me understand the mathematical relationships involved in making allocating a change in future total vehicle sales and change in vehicle segment mix to individual manufacturers. I suggest that this figure be included in future User's Guides.

The approach to this issue taken in OMEGA2 basically assumes that producers maintain their shares within market segments (e.g., pickups, sedans, CUVs) (i.e., they do not compete across these segments). It also assumes that manufacturers do not respond to shifts in the fleetwide sales mix over time by adjusting their own sales mix. For market segments which differ dramatically, like large pickups and subcompacts, this assumption seems reasonable. However, in the demo files, two of the market segments listed are midsized sedan and CUV. The auto market in the U.S. has undergone a very dramatic shift over the past 5-10 years from sedans and station wagons to CUVs and unibody SUVs. Ford, for example, has reduced its offering of midsized sedans to one model: the Mustang. Even this sole model is hardly the traditional family sedan. In constrast, Ford offers six CUVs. (I've excluded the Mustang MachE and Expedition). Thus, Ford, at least, has dramatically shifted its product offerings to adjust to consumers' preference for CUVs over sedans.

The methodology embedded in OMEGA2 is likely to produce increases in total sales for some producers and reductions for others. This could be controversial, particularly since I am unaware of studies showing that the assumptions being made by EPA have actually played out in the market over time. Again, for subcompacts versus large pickup trucks, I believe that the data supporting this assumption exist. I have my doubts that this applies to the same extent for more easily interchanged segments such as sedans and CUVs. A more intricate projection of the effect of a change in sales by market segment may be necessary to accurately reflect producer responses.

6 OMEGA peer review_Example context projection_20211123 (1).xlsx

EPA's Response (RR19): The demo example that the reviewer is referencing provides analysis context projections by size class, but not by manufacturer. As a result, it is necessary to make some assumption about how changes in the sales mix of size classes will impact the relative sales of individual manufactures. The assumption that we use in OMEGA is that each manufacturer retains its relative sales mix position, compared to other manufactures. For example, if one manufacturer makes twice as many pickups as another manufacturer, that relationship will hold in future years even as the overall share of pickups rises or falls.

We could consider another approach where the model used projections of both vehicle sales by size class, and changes of relative size class mix for different manufacturers. However, we are not aware of any such projections, at least for the timeframes required for a typical OMEGA model run.

Role of Consumer Module on Technology Addition, Vehicle Cost and Compliance: Revenue Neutrality in Evaluating Price Cross-Subsidization

OMEGA2 constrains the set of price cross-subsidization (PCS) options to those which maintain the average vehicle price resulting from the current iteration of the Producer module. I believe that this constraint is inconsistent with the constraints placed on the producer in the Producer module. In the Producer module, a wide range of technology and market shares (now understood as only referring to the split of ICEVs and BEVs within each market class) are evaluated using generalized cost and resultant level of GHG credits generated. It is generally assumed that technology-market share combinations with negative generalized costs will not reduce vehicle sales. In fact, they probably increase sales, and increase producer profits. However, acceptable technology-market share combinations are not restricted to those with negative levels of generalized cost. The goal is compliance. Combinations with positive generalized costs are acceptable since compliance with the GHG standards is the primary goal in the running of OMEGA2. Importantly, the acceptance of positive technology-market share combinations means that some loss in sales may result, which in general reduces revenues and profits.

The consumer module takes the two technology-market share combinations with the lowest level of generalized cost which also comply with the GHG standards being considered. The Consumer module then evaluates whether these technology-market share combinations are acceptable, which I take to mean that the price impacts from the Producer module lead the Consumer module to project (within some tolerance) the same levels of total sales and market shares as used by the Producer module.

I suggest that the User's Guide provide a more detailed description of what kinds of conditions can produce a failure to find convergence. I suggest the metric which tends to fail to converge also be discussed. Finally, I suggest that in the case of non-converge, OMEGA2 produce a report (file) which describes the final two estimated solutions (one from the Producer module and the other from the Consumer module. This would allow the user to better understand what OMEGA2 was unable to accomplish.

More broadly, I wonder why a PCS solution which didn't recover all costs should be unacceptable (note the double negative). The addition of technology is clearly going to increase production costs. Technological solutions with positive generalized costs are expected to increase vehicle costs from a consumer's perspective and reduce sales. Reduced sales could or would likely hurt profits. It would seem that PCS solutions which were not revenue neutral would simply reduce profits further. But if compliance is the goal, why should this further reduction in profits be unacceptable? Revenue neutrality seems fine when a solution is possible. However, when it is not, I fail to understand why revenue neutrality should be a show stopper.

One of the demo simulations shows a manufacturer being unable to comply with the GHG standards in the mid 2040's. Why do this occur, since a producer's ability to convert ICEVs to BEVs seems unlimited in this timeframe? If this non-compliance is coming from the Consumer module, this isn't a problem of non-convergence, but a problem of non-compliance due to the requirement of revenue neutrality. If so, this is another kind of situation where revenue-losing PCS solutions should be allowed.

A peer reviewer posed a related question to EPA on this topic.

Exogenous Average Vehicle Price: "Is it necessary in the models structure to assume that "the model automatically only searches for solutions that maintain the overall average vehicle price, thus forcing any cross-subsidization strategies to be revenue neutral"."

EPA Response: "Note that as the producer decisions about vehicle design and technology application change in over multiple producer-policy compliance search iterations, the overall average price *will* change. Still, as the reviewer notes, the overall average price is maintained from the initial producer compliance search within an iteration. We chose to apply this constraint in order to simply the solution search (see the discussion in Q1 on convergence.) While it would be theoretically possible to relax the constraint that average overall price be maintained within an iteration, doing so would require other model revisions, including a change in the objective function, so that instead of minimizing generalized costs, the producer would, for example, maximize the delta between revenue and costs (in order to avoid the issue raised by the commenter of reducing quantities to zero.) EPA is interested in the reviewers' thoughts on this topic, especially regarding the need to maintain the internal consistency of the modeling, and the possible tradeoffs that might be involved with such a revision."

I believe that my suggestion is sort of a "middle road" solution. As long as the model converges, I see no need to change the objective function. My concern is with cases which do not converge. In these cases, I believe that it is likely that the average vehicle price is too high to maintain sales, so sales must be reduced. Assigning a cost to this may be difficult. (EPA refers to estimating a difference between revenue and cost, which I do not believe is performed in the current version of OMEGA2.) Or, the model could include a decrease in sales in this particular model year for this producer as one of the impacts of the scenario.

> **EPA's Response (RR20):** In the most recent version of OMEGA, we have revised the search algorithm so that convergence is always achieved. Please see our response to reviewer comment JM17. If a solution cannot be found with all of the normal constraints applied during the iteration process, the model will converge on the solution that is closest to meeting the compliance target. In other words, the compliance target constraint is relaxed.
>
> The model does provide a log of the producer-consumer iteration steps, so a user can review the metrics from the producer and consumer perspectives that eventually lead to convergence.

Impact of Classifying FWD CUVs as Cars and AWD/4WD as Trucks

Now that OMEGA is incorporating consumer preference into its modeling, I believe that the issue of the regulatory treatment of CUVs should also be addressed. Current GHG regulations define smaller CUVs as passenger cars and these same CUVs with AWD as light trucks. The GHG standards for trucks are less stringent than those for cars at the same footprint, which is the case here. Therefore, manufacturers have a potentially strong incentive to encourage the sale of AWD CUVs in lieu of the sale of FWD CUVs.

I posed the following question to EPA staff: Can a technology include a change in vehicle segment? I'm thinking here of adding AWD or 4WD to a 2WD CUV in order to convert from a passenger car to a light truck. There are other possibilities, of course.

EPA Response: **"**It might be helpful here for us to be specific about how the model handles different types of producer decisions:

1) Changes in non-consumer-facing technology

These are considered as different points in the vehicle cost cloud. The points differ only in terms of generalized cost and emissions rates. The generalized costs can reflect changes in fuel operating costs, but not other consumer valuations specific to the technology

2) Changes in consumer-facing attributes, within a market class
   As with #1, different design choices are represented by different points in the vehicle cloud, except there can be some assumed consumer valuation of the consumer-facing attribute included in the producer generalized cost.
3) Shifts in market class shares
   Instead of choosing between different points within the cost cloud (or more precisely, which point on the composite vehicle frontier curve), the producer is choosing the relative shares of two or more market classes, each with its own composite vehicle frontier curve (in addition to choosing the point from each curve.)

Clearly, the 2WD vs AWD/4WD example given by the reviewer would be a consumer-facing attribute. This could be implemented using #2 above, where AWD is represented as additional points with higher emissions, and with higher production costs which are offset to some extent by some assumed consumer valuation in the generalized costs. Alternatively, AWD could be represented using #3 above as a choice in a different market class, in the same way that the EV vs. ICE decision is handled in the demo example. This would require a revised consumer response in the Consumer Module to estimate the demand for AWD as a function of price and possibly other vehicle attributes. Both options would require some characterization of the consumer's response to AWD. Option #2 would likely be simpler to implement. Option #3 would have the advantage of producing a response that is consistent with heterogeneous consumer demand. E.g. Not all consumers want AWD vehicles, even at zero price premium. **"**

I appreciate this response, as it indicates that it may be possible to accomplish this goal using the current version of OMEGA2. I see two difficulties with approach #2 in this situation. First, EPA mentions including both types of CUVs in a cost cloud. I thought that vehicles could only be combined in a single cost cloud when their market shares were constant, which is explicitly not true in this case.

Second, I wonder how enabling this conversion of FWD CUVs which are cars to AWD CUVs which are trucks would affect the development of cost clouds and curves in the Producer module. The vehicle_simulation file describes technology that changes a vehicle's emissions, but doesn't describe a situation where the vehicle emissions change and the vehicle's market class also changes. In the demo package, the market share of hauling vehicles was fixed, as was the market share of non-hauling vehicles. In the CUV situation, I think that it would be most reasonable to assume that the share of smaller CUVs was fixed, but the split between FWD and 4WD was variable. How would this work if the shares of hauling and non-hauling vehicles were both fixed? Or would this simply require 3 market classes: 1) smaller CUVs, 2) hauling vehicles which were not smaller CUVs and 3) non-hauling vehicles which were not smaller CUVs?

> **EPA's Response (RR21):** Please see our response to JG01. The model does not currently accommodate shifting of reg classes by changing vehicle attributes as a producer decision.

Using GHG Credits to Enable Compliance

I asked the following question of EPA: I Does OMEGA2 ever look backwards as credits are expiring to consider their use prior to expiration?

EPA Response: **"**As implemented for the demo, the producer will attempt to pay back any debits or use any credits immediately. For the demo, credits only expire if the producer was unable to be over-target sufficiently to use them all. Again, those credits that do expire can be observed in the credit logs. We have experimented with the use of the base year banked credits via a couple of strategies (not implemented in the demo) – for example, attempting to use only the expiring credits in a given year, or using the greater of the expiring credits or an amortized amount of all available credits in a given year (which may result in a more level usage of credits over before expiration).

In general, a multi-year credit management strategy involving, for example, being intentionally under- or over-target, would need to be implemented via a higher-level algorithm. We have discussed such algorithms within the OMEGA development team, but these have not been implemented at this time. "

I encourage EPA to develop methods to incorporate the use of credits to enable compliance by producers in OMEGA2 (2.1?). Over the past several years, EPA's own Trends Reports demonstrate that producers have both utilized their own credit banks and purchased credits from other producers to enable compliance. The large size of producers' current credit banks and the role of these credits could play in enabling compliance is a critical factor in EPA's recent GHG rulemaking addressing the 2023-2026 model year standards.

There are a number of simple concepts which could be used to reasonably project credit use and trading. One, assume that all electric producers like Tesla will sell their credits to other producers. This has been demonstrated in past Trends Reports.

Two, with exception, credits should not be allowed to expire. This exception pertains to the expiration of 2010-2015 credits at the end of MY 2021. The size of these credits is very large, the life of these credits is essentially ending as we speak. To allow the expiration of later credits to expire is conceptually no different than assuming a manufacturer will voluntarily consider some of their light trucks as passenger cars when determining compliance. This is a simple giveaway of an asset which has real value. This is unlikely to occur to a significant extent.

Three, producer's compliance costs vary due to their apparent preferences for particular vehicle styles (e.g., low or high mass per footprint, low or high horsepower to mass ratio, etc.). The prices paid for credit purchases in the past are not public knowledge. However, it is reasonable to assume that producers would somehow "split the difference" between the cost of generating a credit by a low cost producer and the compliance cost of the high cost producer. OMEGA2 could output the final incremental cost of each producer's compliance strategy. In OMEGA1, this would have been simple, since sales did not change with the addition of technology, vehicle cost/price, etc. In OMEGA2, this would be more complicated. My personal lack of experience with consumer choice models limits my ability to make specific recommendations here. However, if OMEGA2 will be predicting a reduction in vehicle sales due to further GHG control, the lost sales must apply to some producers. In general, one would expect the lost sales to be greater for those manufacturers facing higher compliance costs than those facing lower compliance costs.

Four, some consideration of producers' desire to retain a cushion of credits to ensure compliance each year and for future years could be acceptable.

> **EPA's Response (RR22):** Please see our response to reviewer comment RR05.

Miscellaneous Comments

General

A Table of Contents for the User's Guide would be useful.

> **EPA's Response (RR23):** The online version of the documentation is the primary version and contains a table of contents. The pdf version was intended as a convenience for the peer reviewers but was not formatted consistently with the primary online version.

Why does the output for an OMEGA2 run include a duplicate version of the source code used? This seems to just require more storage space for each run. A list of the files and their dates would seem sufficient.

EPA's Response (RR24): The model code is saved in oder to provide a comprehensive record. Because the code is made up of text files, the file sizes are only several MB in total, which is extremely small compared to the overall model output.

GUI

When I entered a new batch file into the GUI, the comment box indicated that I had an invalid output directory. One can only change the name of the batch file and output directory in two separate steps. Instead of a comment that I did something wrong after completing the first step, I suggest an approach which prompts the user more clearly. One possibility would be to add two separate "buttons" which indicate that the use wants to update the input batch file or the output directory. Each button, when clicked would highlight and allow the user to update the indicated file/directory. Also, if there were already output in the output directory and the user clicked "run", it would be useful if OMEGA asked the user if they wanted to replace the existing output, like Windows does when you try to save a new file using a previously existing file name.

EPA's Response (RR25): Thank you for the recommendation.

Cars vs. Trucks and Hauling vs. Non-Hauling

I cannot find where OMEGA classifies individual vehicles into hauling and non-hauling segments. The vehicles files labels vehicles as car or truck. The User's Guide refers to GHG targets for hauling and non-hauling vehicles (p. 19). It is possible that non-hauling and hauling are synonyms for passenger car and light truck. If so, I found this confusing.

EPA's Response (RR26): In the user-definable market class package, there is a get_vehicle_market_class method that assigns a market class to each vehicle based on the user definition. The list of names of the market classes is provided by the user in the 'market_classes' input file. Note that for whatever classes the user wishes to define, the user will need to update other input files that contain market class distinctions accordingly.

Control of the Consumer Module

I recommend that EPA add a button in the GUI which would disable consumer preferences, or describe what values to enter in the sales_share_params-cntxt_a file which would effectively disable this feature. One, this would allow the results of OMEGA2 to be compared to past analyses using OMEGA1. Two, it would reveal the significance of the simulation of consumer preferences on the model's projections and alert the user or observer to relative importance of this aspect of the modeling. For example, total vehicle sales increase by roughly 250,000 vehicles in 2034 and 2035 under the Policy Alternative. This is substantial and will be noticed and questioned as to its importance and justification.

EPA's Response (RR27): Thank you for the recommendation. There are too many various model settings to include all of them in the GUI, especially since each session might need to be defined separately. In the most recent version of the model, we have implemented a 'producer_shares_mode' developer option that can be set in the batch file, which when set to 'True' would exhibit the behavior that the reviewer is suggesting.

3.2. Running the Demo Example

A brief description of the purpose of the Configuration File would be helpful. I think that this filename comes out of the blue.

Also, the passive tense in the sentence obscures who is performing these actions (e.g., "A model run is created", "an existing Configuration File is used"). These options are not shown on the Run Model tab. How does one load an existing Configuration File?

> **EPA's Response (RR28):** The documentation contains a description of how the configuration file can be used to simplify the loading of a previous run.

3.2.1. Creating a New Model Run From The Demo Example

A prompt asking the user if they want to save the Configuration File would be helpful.

The User's guide states: "Use the file menu to save the new Configuration File. (Optional)". References to the "File" menu at the top of the window should be in quotes, bold or somehow highlighted in the User Guide text so that the user knows what this is. Otherwise, it can be easily confused with a file directory where OMEGA files are stored.

> **EPA's Response (RR29):** Thank you for the recommendation. The documentation has been updated.

3.2.2.1. Set Model Run Options

Example Multiprocessor Batch File:

This could not be tested as the Event Monitor states that the multiprocessor option is disabled. However, if it ever is enabled, it would be helpful to know what values or text needs to be modified by the user in the example file and what is generic and does not need to be changed. For example, is it simply a matter of the number of CPU cores? Or does the "%BasePath% need to be changed, as well?

Figure 3.8

The upper two graphs shown in Figure 3.8 show the CO2e targets by market segment. The legend shows four lines, hauling ICEVs, non-hauling ICEVs, hauling BEVs and non-hauling BEVs. However, only two lines are shown in each of the two upper graphs, those pertaining to the two ICEV market segments. I don't believe that this depiction is accurate. I don't think that the two curves describe the CO2e targets just for ICEVs. Instead, I believe that they apply to all hauling and all non-hauling vehicles. If I am correct, this should be corrected.

> **EPA's Response (RR30):** This portion of the GUI was used as an example feature and has been removed as the detailed information is available in the output files.

The lower two graphs show the average certification CO2e values for the same four market segments. Now there are four distinct curves. I can't be sure whether these graphs are realistic or not. However, there are some aspects of the two ICEV curves for the two GHG scenarios which appear unreasonable.

Starting with the NoActionPolicy scenario, upstream BEV emissions are first being counted in 2035. The CO2e emissions from hauling ICEVs decrease significantly (40-45 g/mi CO2e, or 10-15% in relative terms) between 2034 and 2035. This decrease is unrealistically large for a single model year (see my comment above vehicle redesign cycles). Since the best hybrid systems only reduce GHG emissions by ~20-25%, this implies that 50-60% of hauling ICEVs were hybridized in one model year. Then, hauling ICEV emissions in 2036 and beyond increase over 2035 levels. Is OMEGA2 removing technology between 2035 and 2036. If so, I believe that this is problematic. These emissions then decrease significantly again between 2044 and 2045. I don't see any substantial changes in the market shares for the four market segments occurring between 2044 and 2045. What is the cause of this decrease in hauling ICEV emissions in 2045?

EPA's Response (RR31): The results in the demo example did not have redesign cycles. Please see our response to RR11.

Figure 3.9

Why are certification and compliance CO2e levels shown on both a MY and CY basis? There are differences between the two types of years, but these differences have usually been ignored in prior versions of OMEGA and in the Volpe CAFE model. While MY sales begin in the previous CY, the VMT of these early sales in the previous CY is compensated to some extent by the fact that MY sales occurring in the same CY usually are not driven for a full year in that CY.

EPA's Response (RR32): The model year curve on the auto-generated compliance plot shows the final Mg values after credit transfers to or from that model year. The calendar year curve shows the Mg values for new vehicles in that calendar year (i.e. model year age 0).

As in the past, for new vehicles we are not making any distinction between a calendar year and model year for which month the year begins.

Figure 3-10

Under the NoActionPolicy scenario, there is a sudden increase in non-hauling BEV sales in 2040, due to a minimum BEV sales requirement. I don't recall the User's Guide discussing minimum sales requirements for specific market segments, though I found the input file which describes them. How do these minimum sales requirements interact with the Consumer module? Does OMEGA simply prevent the Consumer module from reducing relevant market shares below their minimum? In the absence of a minimum market share, when OMEGA2 fails to converge on a solution, I presume that this is due to the Producer module wanting to increase the sale of lower emitting vehicles (probably BEVs), but the Consumer module rejecting this because of a consumer preference for ICEVs at the prices being provided to the module. How does OMEGA2 get around this conundrum when there is a sales minimum?

Under the NoPolicyAction scenario, why is the minimum sales level for non-hauling BEVs in 2045-50 lower than from 2040-45 (and worse, negative)?

Under the ActionAlternative scenario, non-hauling BEV sales increase substantially in 2048 in an attempt to produce credits for carryback to 2046 and 2047. This attempt fails and the manufacturer is in non-compliance. This demonstrates the need to include more broad and realistic simulation of credit generation and use in OMEGA2. OMEGA2 apparently starts looking for ways to generate credits when the 3 year window for carrying back credits is about to expire. This is good in and of itself, but hardly a robust use of credits to aid compliance.

This section of the User's Guide simply states that the producer could not comply with the GHG standards given the modeled consumer response and the specified limits on producer price cross-subsidization. I suggest that the guide present the alternative that the limits on producer price cross-subsidization could be expanded to determine what degree of subsidization would be require to enable compliance. This issue is addressed in another comment and may be resolved through the modification to OMEGA2 suggested there.

In general, the guide is written with only one No Action scenario and one Action scenario in mind. In reality, no model does everything well and realistically. I suggest a discussion where the user is instructed to review the results for realism and determine if another run with slightly different inputs would yield more realistic results. The current version of OMEGA2 is very flexible and doesn't set much in stone. The user is responsible for nearly everything. This onus on the user should be made clear. The only exception would be the reproduction of OMEGA2 runs made by EPA using input file provided by EPA.

EPA's Response (RR33): Thank you for the recommendation. We will consider adding emphasis on the importance of the user inputs and assumptions in a future version of the documentation.

APPENDIX A

RESUMES OF SELECTED REVIEWERS

Sujit Das

VITA

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

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 – Present	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 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**," P**aper 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

John M. German

PROFESSIONAL EMPLOYMENT

Sept. 2018 to present JG AUTOMOTIVE CONSULTING, LLC

- Consulting services for automotive technology, compliance and enforcement, policy, rulemaking, and consumer behavior.

January 2009 to August 2018 SENIOR FELLOW, INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

- Primary responsibility for technology innovation and U.S. policy development.
- Part of team that conducted testing uncovering VW defeat devices and efforts to improve enforcement worldwide.
- Wrote series of six technology assessment papers in cooperation with suppliers.

February 1998 to January 2009 MANAGER, ENVIRONMENTAL AND ENERGY ANALYSIS, PRODUCT REGULATORY OFFICE, AMERICAN HONDA MOTOR CORPORATION

- Provide policy and technical analyses on vehicle emissions and energy issues.
- Liaison between Honda R&D, both in the U.S. and Japan, and external organizations, including government agencies, environmental groups, other manufacturers, academia, and state representatives.
- Primary Honda representative on fuel economy and global warming issues, including testifying before Congress six times, writing testimony, writing responses to CAFE rulemaking, and making presentations.

October, 1986 to January, 1998 SENIOR TECHNICAL ADVISOR, U.S. EPA OFFICE OF MOBILE SOURCES.

- Supervised up to 8 employees, managed development of regulations and guidance, and served as technical consultant on a wide variety of issues.
- Technical manager for study on Tier II emission standards for cars and light trucks.
- Designed and managed extensive research project evaluating in-use driving behavior and its impact on emissions in support of new Supplemental Federal Test Procedure regulations and requirements. Created and managed extensive usage of teams across organizational boundaries.
- Managed the development of the Nonroad Engine and Vehicle Emission Study.
- Managed rulemaking for Cold Temperature Carbon Monoxide Standards.
- Worked with transportation planners to help create and develop a computer simulation model for vehicle emissions (as part of 2011-13 NCHRP project).
- EPA senior technical advisor on greenhouse gas and fuel economy issues, including CAFE alternatives, in-use fuel economy factors, and advanced technology. Active member of EPA global warming team and an inter-agency modeling team.
- Created and managed rulemaking assessing LDT CAFE test procedure adjustments.
- Developed policy guidance for driver-selectable devices, coastdown procedures, dynamometer power absorption settings, and model year definition and duration.

May, 1985 to Sept., 1986 TEAM LEADER, U.S. EPA OFFICE OF MOBILE SOURCES.

- Supervised 3 employees and managed manufacturer motor vehicle emissions compliance program.
- Wrote guidance on numerous certification procedure issues.

December, 1981 to May, 1985 ENGINEERING SUPERVISOR, CHRYSLER POWERTRAIN.

- Supervised 6 engineers, supported product planning, and developed strategies to optimize vehicle fuel economy and to ensure compliance with all fuel economy requirements.
- Chrysler's principal technical advisor on fuel economy and methods to improve CAFE
- Provided technical analyses and written responses to proposed regulations.
- Represented Chrysler on fuel economy matters with EPA and NHTSA.
- Provided CAFE projections and analyzed CAFE impacts of future product changes.
- Team leader of a project to implement Shift Indicator Lights.

November, 1976 to December, 1981 ENGINEER, CHRYSLER POWERTRAIN.

Designed and implemented, from scratch, Chrysler's system to comply with extensive EPA fuel economy regulations issued in 1975. Also coordinated fuel economy testing, served as liaison with EPA, helped write responses to proposed regulations, and worked on special projects.

AWARDS and ADVISORY COMMITTEES

2015	**ECOBEST AWARD** from Autobest.org, for uncovering the VW diesel defeat device
2010-13	**NATIONAL RESEARCH COUNCIL** – Committee on Transitions to Alternative Vehicles and Fuels; vehicle subcommittee lead.
2011-13	**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM** – Committee on Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on State Departments of Transportation
2008	**NATIONAL RESEARCH COUNCIL** – Committee for a Study of Potential Energy Savings and Greenhouse Gass Reductions from Transportation
2006	**SAE ENGINEERING MEETINGS OUTSTANDING ORAL PRESENTATION AWARD,** for "It's a High-MPG Vehicle Issue, Not a Hybrid Issue", SAE Government/Industry Mtg.
2004	**BARRY MCNUTT AWARD FOR EXCELLENCE IN AUTOMOTIVE POLICY ANALYSIS** 1st recipient of annual award from the SAE
2002-2003	**ADVISORY BOARD**, Advanced Power Technology Alliance, Center for Automotive Research, Ann Arbor, MI
2002-2003 2001-2002	**SAE INDUSTRIAL LECTURESHIP PROGRAM**, to promote interaction between practicing engineers and faculty and students via campus visits
1995	**SILVER MEDAL**, U.S. EPA for strategies to reduce air pollution from nonroad engines
1994	**EPA SCIENCE ACHIEVEMENT AWARD** in Air Quality. Only person in EPA's Office of Mobile Sources ever to receive this award.
1993	**OUTSTANDING TECHNICAL COMMUNICATION** in the 1992-93 Society for Technical Communication of Southeastern Michigan Technical Publications Competition, for "Nonroad Engine and Vehicle Emission Study"
1992	**BRONZE MEDAL**, U.S. EPA for the "Nonroad Engine and Vehicle Emission Study"
1991	**BRONZE MEDAL**, U.S. EPA for the Cold Temperature Carbon Monoxide Rulemaking

LEADERSHIP TRAINING

2000	Honda Leader's Program – Center for Creative Leadership
1997	Modeling and Computer Simulation of Internal Combustion Engine--U. of Mich. course
1996-7	Excellence in Government Fellows Program--Council for Excellence in Government

1995	Diversity Workshops - University of Michigan
1993	Total Quality Management
1992	Looking Glass Workshop: Leadership in Multilevel Organizations – Creative Leadership
1991	Use of Consultative Methods - EPA Institute
1990	Work Group Leadership - Conservation Foundation
1989	Regulation Development in EPA - EPA
1988	Planning Effective Meetings - EPA
1987	Zenger-Miller Supervision program on Behavior Modeling - EPA
1985	Personnel Management for Managers and Supervisors - OPM
1984	Interaction Management - Chrysler Institute
1982	Organizational Leadership and Productivity - Mansare Corp.
1982	Leadership Effectiveness Training - Chrysler Institute
1981	Supervisory Skills Training - Chrysler Institute

EDUCATION

1980-1984	University of Michigan. Completed 34 hours towards M.B.A. GPA: 7.9 (A=8.0)
1970-1975	University of Michigan, B.S., Physics (minor in Math).
	Honors: National Merit Finalist, Honors Program, Dean's List
	Activities: U. of Michigan Marching Band and Concert Band

PUBLICATIONS

J. German, "How things work: OMEGA modeling case study based on the 2018 Toyota Camry", working paper published 2018.02.21 by the ICCT. https://theicct.org/publications/how-things-work-omega-modeling-case-study-based-2018-toyota-camry

J. German, "U.S. fuel economy trends reflect a business strategy, not a technology challenge", posted 19 January 2018. https://theicct.org/blog/staff/us-fuel-economy-trend-reflects-business-strategy-not-tech-challenge

J. German, "Technology Leapfrog: Or, all recent auto technology forecasts underestimate how fast innovation is happening", posted 25 September 2017. https://theicct.org/blog/staff/technology-leapfrogging

A. Isenstadt, J. German, "Diesel Engines", 2017, published by ICCT. http://www.theicct.org/diesel-engines

A. Isenstadt, J. German (ICCT), M. Dorobantu (Eaton), "Naturally aspirated gasoline engines and cylinder deactivation". 2017, published by ICCT. http://www.theicct.org/naturally-aspiratedgas-engines-201606

Meszler, D., German, J., Mock, P., & Bandivadekar, A. (2016). CO2 reduction technologies for the European car and van fleet: A 2025-2030 assessment. International Council on Clean Transportation. https://theicct.org/publications/co2-reduction-technologies-european-car-and-van-fleet-2025-2030-assessment

A. Isenstadt, J. German (ICCT), M. Dorobantu (Eaton), D. Boggs (Ricardo), T. Watson (JCI), "Downsized, boosted gasoline engines", 2016, published by ICCT. http://www.theicct.org/downsized-boosted-gasoline-engines

A. Isenstadt, J. German (ICCT), P. Bubna, M. Wiseman (Ricardo), U. Venkatakrishnan, L. Abbasov (SABIC), P. Guillen, N. Moroz (Detroit Materials), D. Richman (Aluminum Assoc.), G. Kolwich (FEV), “Lightweighting technology development and trends in U.S. passenger vehicles”, 2016, published by ICCT. http://www.theicct.org/lightweighting-technology-development-and-trends-us-passenger-vehicles

S. Osborne, J. Kopinsky, S. Norton (ITB), A. Sutherland, D. Lancaster, E. Nielsen (BorgWarner); A.Isenstadt, J. German (ICCT), “Automotive thermal management technology”, 2016, published by ICCT. http://www.theicct.org/automotive-thermal-management-technology

John German, “Hybrid vehicles: Trends in technology development and cost reduction”, 2015, published by ICCT. http://www.theicct.org/hybrid-vehicles-trends-technology-development-and-cost-reduction

V. Franco, F. Posada, J. German, P. Mock, "Real-world exhaust emissions from modern diesel cars", October 2014, published by ICCT. http://theicct.org/real-world-exhaust-emissions-modern-diesel-cars

P. Mock, U. Tietge, V. Franco, J. German, A. Bandivadekar (ICCT), N. Ligterink (TNO), U. Lambrecht (IFEU), J. Kühlwein (KISU), I. Riemersma (Sidekick Project Support), "From laboratory to road: A 2014 update", September 2014, published by ICCT. http://theicct.org/laboratory-road-2014-update

John German, "U.S. Tier 3 vehicle emissions and fuel quality standards, final rule", March 2014, published by ICCT. http://theicct.org/us-tier-3-vehicle-emissions-and-fuel-quality-standards-final-rule

D. Meszler, J. German, P. Mock, A. Bandivadekar, J. Tu, "Summary of Eastern EU labor rate impacts on EU cost curves", February 2014, published by ICCT. http://theicct.org/summary-eastern-eu-labor-rate-impacts-eu-cost-curves

S. Searle, F. Posada, C. Malins, J. German, "Technical barriers to the consumption of higher blends of ethanol", February 2014, published by ICCT. http://theicct.org/technical-barriers-consumption-higher-blends-ethanol

John German, "Invited Commentary: The Future of U.S. Natural Gas is Utilities, Export, and Trucks, not Cars", Current Sustainable/Renewable Energy Reports, Springer International Publishing AG 2014.

A. Bandivadekar, T. DeFries, J. German, S. Kishan, F. Posada, M. Sabisch, "In-Use Fuel Economy and CO2 Emissions Measurement using OBD Data on US Light-Duty Vehicles", SAE 2014-01-1623, April 2014.

F. Posada and J. German, "Measuring in-use fuel economy: Summary of pilot studies", December 2013, published by ICCT. http://theicct.org/measuring-in-use-fuel-economy-summary-pilot-studies

A. Bandivadekar, J. German, U. Lambrecht, N. Ligterink, P. Mock, "From Laboratory to Road", May 2013, published by ICCT. http://theicct.org/laboratory-road

A. Bandivadekar, J. German, D. Meszler, P. Mock, "Initial processing of Ricardo vehicle simulation modeling CO2 data", February 2013, published by ICCT. http://theicct.org/initial-processing-ricardo-vehicle-simulation-modeling-co2-data-0

A. Bandivadekar, J. German, D. Meszler, P. Mock, "Mass reduction impacts on EU cost curves", February 2013, published by ICCT. http://theicct.org/mass-reduction-impacts-eu-cost-curves

D. Meszler, J. German, P. Mock, and A. Bandivadekar, "EU cost curve development methodology", November 2012, published by ICCT. http://www.theicct.org/eu-cost-curve-development-methodology

D. Meszler, J. German, P. Mock, A. Bandivadekar, "Initial processing of Ricardo vehicle simulation modeling CO2 data", July 2012, published by ICCT. http://www.theicct.org/initial-processing-ricardo-vehicle-simulation-modeling-co2-data

F. Posada Sanchez, A. Bandivadekar, and J. German, Estimated Cost of Emission Reduction Technologies for Light-Duty Vehicles, published by ICCT, June 2012. http://theicct.org/estimated-cost-emission-reduction-technologies-ldvs

P. Mock, J. German, A. Bandivadekar, and I. Riemersma,"Discrepancies between type-approval and real-world fuel consumption and CO2 values in 2001-2011 European passenger cars", published by ICCT, April 2012. http://www.theicct.org/fuel-consumption-discrepancies

D. Kodjak, A. Bandivadekar, J. German, and N. Lutsey, "The regulatory engine: How smart policy drives vehicle innovation", published by ICCT, January 2011. http://www.theicct.org/regulatory-engine

John German, Hybrid Powered Vehicles, SAE Technology Profile T-119, 2nd edition, book published by Society of Automotive Engineers, Warrendate, Pa., 2011.

J. German and N. Lutsey, “Size or Mass? The Technical Rationale for Selecting Size as an Attribute for Vehicle Efficiency Standards”, July 2010, published by ICCT. http://www.theicct.org/2010/08/size-or-mass/

J. German and D. Meszler, “Best Practices for Feebate Program Design and Implementation”, April 2010, published by ICCT. http://www.theicct.org/2010/04/feebate-best-practices/

John German, "Leadtime, Customers, and Technology: Technology Opportunities and Limits on the Rate of Deployment". Reducing Climate Impacts in the Transportation Sector. D. Sperling and J. Cannon, Springer Press, 2008.

D. Greene, J. German, and M. Delucchi, "Fuel Economy: The Case for Market Failure ". Reducing Climate Impacts in the Transportation Sector. D. Sperling and J. Cannon, Springer Press, 2008.

J. German, "Reducing Vehicle Emissions Through Cap and Trade Schemes". Driving Climate Change: Cutting Carbon from Transportation. D. Sperling and J. Cannon, Elseview & Academic Press, 2006.

Hybrid Gasoline-Electric Vehicle Development, edited by John German, SAE PT-117, 2005.

John German, “Hybrid Electric Vehicles”, Encyclopedia of Energy, Elsevier & Academic Press, 2004

John German, Hybrid Powered Vehicles, SAE Technology Profile T-119, book published by Society of Automotive Engineers, Warrendate, Pa., 2003.

John German, “Hybrid Vehicles Go to Market”, TR News #213, March-April 2001.

John German, "VMT and Emission Implications of Growth in Light Truck Sales", Air and Waste Management Association Emission Inventory Conference proceedings, Oct. 1997.

J. Alson, J. German, K. Gold, R. Larson, and M. Wolcott, "Transportation Energy Demand Models: Why They Underestimate Greenhouse Gas Emissions", Climate Change Analysis Workshop Proceedings, June 6-7, 1996.

John German, "Off-Cycle Emission and Fuel Efficiency Considerations", Asilomar conference on Transportation and Energy, 1995.

John German, "Observations Concerning Current Motor Vehicle Emissions", SAE 950812, Feb. 1995.

J. Koupal and J. German, "Real-Time Simulation of Vehicle Emissions Using VEMISS", CRC On-Road Vehicle Emissions Workshop, April 1995.

S. Sheppard, J. Fieber, J. Cohen, and J. German, "Cold Start Motor Vehicle Emissions Model", Air and Waste Management Association, Cincinnati, 1994. Paper ID: 94-RP107B.02

P. Enns, J. German, and J. Markey, "EPA's Survey of In-Use Driving Patterns: Implications for Mobile Source Emission Inventories", AWMA/CARB Specialty Conference on Emission Inventory, Pasadena, CA, October, 1993.

Jeremy J. Michalek

CURRICULUM VITAE

Engineering and Public Policy • Mechanical Engineering • Carnegie Mellon University

ACADEMIC APPOINTMENTS

Professor, Carnegie Mellon University

Mechanical Engineering (July 2014 – *present*)

Engineering and Public Policy (July 2014 – *present*)

Associate Professor, Carnegie Mellon University

Mechanical Engineering (July 2010 – June 2014)

Engineering and Public Policy (July 2011 – June 2014)

Engineering and Public Policy, affiliated (July 2010 – June 2011)

Assistant Professor, Carnegie Mellon University

Mechanical Engineering (July 2005 - June 2010)

Engineering and Public Policy, affiliated (June 2007 – June 2010)

Research Economist

National Bureau of Economic Research (Apr 2018 – Mar 2019)

Director, Carnegie Mellon Vehicle Electrification Group (Jan 2012 – *present*)
Co-Director, Carnegie Mellon Vehicle Electrification Group (Jan 2009 – Jan 2012)

http://www.cmu.edu/cit/veg

Director, Carnegie Mellon Design Decisions Laboratory (July 2005 - *present*)

http://www.cmu.edu/me/ddl

Postdoctoral Research Fellow (Jan 2005 - June 2005)

Department of Mechanical Engineering

University of Michigan, Ann Arbor, MI

EDUCATION

Ph.D. Mechanical Engineering, University of Michigan, 2005

M.S. Mechanical Engineering, University of Michigan, 2001

B.S. Mechanical Engineering, Minor in Engineering Design, Carnegie Mellon University, 1999

RESEARCH INTERESTS

Energy and transportation: Economic, environmental, social, technical, behavioral, and policy aspects of vehicle and transportation systems

Vehicle electrification, automation, and sharing

Optimization methods and applications

Consumer choice models *Jeremy J. Michalek • Curriculum Vitae*

TEACHING INTERESTS

Engineering, economic, and environmental modeling, analysis, and decision-making

Mathematical modeling, numerical methods, and optimization

Energy and transportation: Economic, environmental, social, technical, behavioral, and policy aspects of vehicle and transportation systems

Innovation and critical thinking in design, defining and working with open-ended problems

PUBLICATIONS

Peer-Reviewed Journal Publications

[1] Bruchon, M., I. Azevedo and J.J. Michalek (2021) "Effects of air emission externalities on optimal ridesourcing fleet electrification and operations," *Environmental Science & Technology*, online Feb 18, 2021.

[2] He, Guannan, J. Michalek, S. Kar, Q. Chen, D. Zhang and J. Whitacre (2021) "Utility-scale portable energy storage systems," *Joule* v5 n2 p379-392.

[3] Ward, J., J.J. Michalek, C. Samaras, I. Azevedo, A. Henao, C. Rames, T. Wenzel (2021) "The impact of Uber and Lyft on vehicle ownership, fuel economy & transit across U.S. cities," *iScience* v21 n1 p101933.

[4] Yip, A., K. Whitefoot and J.J. Michalek (2021) "Implications of competitor representation for profit-maximizing optimal design," in press, *ASME Journal of Mechanical Design*.

[5] Ward, J., J.J. Michalek and C. Samaras (2021) "The air pollution, greenhouse gas and traffic externality benefits and costs of shifting private vehicle travel to ridesourcing services," in press, *Environmental Science & Technology*.

[6] Ward. J.W., J.J. Michalek, I.L. Azevedo, C. Samaras, P. Ferreira (2019) "Effects of on-demand ridesourcing on vehicle ownership, fuel consumption, vehicle miles traveled, and emissions per capita in US states," *Transportation Research Part C: Emerging Technologies* v108 p289-301.

[7] Helveston. J.P., S.M. Seki, J. Min, E. Fairman, A.A. Boni, J.J. Michalek, I.M.L. Azevedo (2019) "Choice at the pump: measuring preferences for lower-carbon combustion fuels," *Environmental Research Letters*, v14 n8 084035.

[8] Jenn, A., I.L. Azevedo and J.J. Michalek (2019) "Alternative-fuel-vehicle policy interactions increase U.S. greenhouse gas emissions," *Transportation Research Part A: Policy and Practice*, v124 p397-407.

[9] Ward, J.W., J.J. Michalek, I.L. Azevedo, C. Samaras, P. Ferreira (2019) "Effects of on-demand ridesourcing on vehicle ownership, fuel consumption, vehicle miles traveled, and emisssions per capita in U.S. states," *Transportation Research Part C: Emerging Technologies*, v108 p289-301.

[10] Helveston, J., E. Feit and J.J. Michalek (2018) "Pooling stated and revealed preferences in the presence of endogeneity," *Transportation Research Part B: Methodological*, v109 p70-89.

[11] Yip, A., J.J. Michalek and K. Whitefoot (2018) "On the implications of using composite vehicles in choice model prediction," Transportation Research Part B: Methodological, v116 p163-188.

[12] Sakti, A., I.M.L. Azevedo, E.R.H. Fuchs, J.J. Michalek, K.G. Gallagher and J.F. Whitacre (2017) "Consistency and robustness of forecasting for emerging technologies: the case of Li-ion batteries for electric vehicles," *Energy Policy* v106 p415-426.

[13] Yuksel, T., S. Litster, V. Viswanathan, and J.J. Michalek (2017) "Plug-in hybrid electric vehicle LiFePO4 battery life implications of thermal management, driving conditions, and regional climate" *Journal of Power Sources*, v338 n15 p49-64.

[14] Haaf, C.G., W.R. Morrow, I. Azevedo, E. Feit and J.J. Michalek (2016) "Forecasting light-duty vehicle demand using alternative-specific constants for endogeneity correction vs. calibration," *Transportation Research Part B: Methodology*, v84 p182-210.

[15] Jenn, A., I.L. Azevedo and J.J. Michalek (2016) "Alternative fuel vehicle adoption increases fleet gasoline consumption and greenhouse gas emissions under United States corporate average fuel economy policy and greenhouse gas emissions standards," Environmental Science & Technology, v50 n5 p.2165-2174.

[16] Weis, A., P. Jaramillo and J.J. Michalek (2016) "Consequential life cycle air emissions externalities for plug-in electric vehicles in the PJM interconnection," Environmental Research Letters, v11 n2 024009.

[17] Yuksel, T., M. Tamayao, C. Hendrickson, I. Azevedo and J.J. Michalek (2016) "Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of electric and gasoline vehicles," Environmental Research Letters, v11 n4 044007.

[18] Helveston, J.P., Y. Liu, E. Feit, E. Fuchs, E. Klampfl, and J.J. Michalek (2015) "Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the U.S. and China," Transportation Research Part A: Policy and Practice, v73 p96-112.

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Commentary and Testimony

[99] Bruchon, M. and J. Michalek, "Comment on California Air Resources Board's Proposed Clean Miles Standard," Public Comment, May 17, 2021.

[100] Michalek, J. and K. Whitefoot, "Comment on the Notice of Proposed Rulemaking for the 'Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks'" Public Comment, Docket No. NHTSA-2018-0067 and EPA-HQ-OAR-2018-0283, October 26, 2018, U.S. Federal Register.

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Dissertations and Theses:

[107] Michalek, J.J., (2005) Preference Coordination in Engineering Design Decision-Making, Ph.D. Dissertation, Department of Mechanical Engineering, University of Michigan. Committee: Panos Papalambros*, Fred Feinberg, Steven Skerlos, Richard Gonzalez.

[108] Michalek, J.J. (2001) Interactive Layout Design Optimization, M.S. Thesis, Department of Mechanical Engineering, University of Michigan, Ann Arbor, Michigan, USA, 2001. Committee: Panos Papalambros*, Kazuhiro Saitou.

ADVISING

Ph.D. Research

Shiau, Ching-Shin Norman – *Design Decision Making for Market Systems and Environmental Policy with Vehicle Design Applications*, Ph.D. Mechanical Engineering, (2006-2010). Present position: Design Engineering Staff Engineer, Seagate Technologies, Taiwan.

Khajavirad, Aida – *Convexification Techniques for Global Optimization of Nonconvex Nonlinear Optimization Problems*, Ph.D. Mechanical Engineering (2006-2011), co-advised with Nick Sahinidis. Present position: Assistant Professor, Operations Research and Industrial Engineering, Department of Mechanical Engineering, University of Texas at Austin.

Karabaşoğlu, Orkun – *Influence of Driving Patterns and Optimal Robust Powertrain Combined Design and Control of Plug-in Vehicle Cost, Life Cycle Emissions, Component Sizing, and Battery Stress*, Ph.D. Mechanical Engineering (2008-2013). Present position: Assistant Professor, Electrical and Computer Engineering, SYSU-CMU Joint Institute of Engineering, Visiting Professor, Electrical and Computer Engineering, Carnegie Mellon University.

Traut, Elizabeth – *Life Cycle Cost and Environemtnal Implications of U.S. Electric Vehicle and Charging Infrastructure Scenarios*, Ph.D. Mechanical Engineering (2008-2013), co-advised with Prof. Chris Hendrickson. Present position: Postdoctoral Research Fellow, Civil and Environmental Engineering, Carnegie Mellon University.

Resende, Camilo – Ph.D. student, Mechanical Engineering (2009-2010), left program for medical school.

Sakti, Apurba – *Quantification of Performance and Cost Trajectory of Li-ion Battery Designs for Personal Vehicle Electrification in the Near Future*, Ph.D. Engineering & Public Policy (2010-2013), co-advised with Prof. Jay Whitacre. Present Position: Postdoctoral Associate, Energy Initiative and Chemical Engineering, Massachusetts Institute of Technology.

Haaf, Christine Grace Heckmann – *Vehicle Demand Forecasting with Discrete Choice Models*, Ph.D. Mechanical Engineering (2010-2014). Present Position: Visiting Researcher, King Abdullah Petroleum Studies and Research Center (KAPSARC).

Jenn, Alan – *Advanced and Alternative Fuel Vehicle Policies: Regulations and Incentives in the United States*, Ph.D. Engineering and Public Policy (2014), officially advised by Prof. Inês Azevedo but I co-advised several studies. Present Position: Postdoctoral Researcher, University of California, Davis.

Min, Jihoon – *Energy Efficient Lighting: Consumer Preferences, Choices, and System Wide Effects*, Ph.D. Engineering and Public Policy (2010-2014), co-advised with Prof. Inês Azevedo. Present Position: Research Scholar, International Institute for Applied Systems Analysis.

Tamayao, Mili-Ann – *Urbanization and Vehicle Electrification in the U.S.: CO2 Emissions Estimation and Implications for Climate Policy*, Ph.D. Engineering and Public Policy (2012-2014), co-advised with Prof. Chris Hendrickson. Present Position: Assistant Professor, Industrial Engineering and Operations Research, and Deputy Executive Director, National Engineering Center, University of the Philippines.

Weis, Allison – *Electric Vehicles and the Grid: Interactions and Environmental and Health Impacts*, Ph.D. Engineering and Public Policy (2010-2014), co-advised with Prof. Paulina Jaramillo. Present Position: Senior Stationary Storage Modeling Engineer, Tesla Motors.

Yüksel, Tuğçe – *Quantification of Temperature Implications and Investigation of Battery Design Options for Electrified Vehicles*, Ph.D. Mechanical Engineering (2010-2015). Present Position: Sabanci University.

Helveston, John – *Development and Adoption of Plug-in Electric Vehicles in China: Markets, Policy, and Innovation*, Ph.D. Engineering and Public Policy (2011-2016), co-advised with Prof. Erica Fuchs. Present Position: postdoctoral researcher, Boston University.

Yip, Arthur – *Integrated Modelling of Consumer Choice, Producer Decisions, and Policy Design in the Automotive Market*, Ph.D., Engineering and Public Policy (2015 – 2020), co-advised with Prof. Kate Whitefoot.

Ward, Jacob – *The Energy and Environmental Effects of New and Future Mobility: Econometric and Simulation Analysis of Ridesourcing Services Uber and Lyft*, Ph.D., Engineering and Public Policy (2016 – 2020), co-advised with Prof. Inês Azevedo and Prof. Costa Samaras.

Bruchon, Matthew – Ph.D. candidate, Engineering and Public Policy (2017 – pres), co-advised with Prof. Inês Azevedo.

Forsythe, Connor – PhD. student, Mechanical Engineering (2018 – pres), co-advised with Prof. Kate Whitefoot.

Burns, Aaron – Ph.D. student, Engineering and Public Policy (2020 – pres), co-advised with Prof. Constantine Samaras.

Koling, Adam – PhD. student, Engineering and Public Policy (2021 – pres), co-advised with Prof. Daniel Armanios.

Vicente, Johnathan – Ph.D. student, Mechanical Engineering (2021 – pres), co-advised with Prof. Kate Whitefoot.

M.S. Research Project-Based Degree

Li, Yanjing – *Diagonal Quadratic Approximation for Parallel Computing with Analytical Target Cascading*, M.S. Mathematical Sciences, 2006

Swamy, Surya – *Global Optimization of Mixed-Integer Nonlinear Systems using Decomposition and Lagrangian Branch-and-Cut*, M.S. Mechanical Engineering, 2007

Kaushal, Nikhil – *Optimal Plug-in Hybrid Electric Vehicle Design and Allocation for Diverse Charging Patterns*, M.S. Mechanical Engineering, 2009

Krishnakumar, Varun – *Global Design Optimization using Black-Box Optimization Techniques*, M.S., Mechanical Engineering, 2009

Tsu-Wei Cherng – *Charging Infrastructure for Electric Vehicles*, Mechanical Engineering, 2011-2012

Gao, Nan -- *Battery Degradation and Thermal Management for Plug-in Vehicles*, M.S. Mechanical Engineering, 2013-2014

Jennings, Stephanie – *Forecasting Technology Purchase Choice Using Composites*, M.S. Mechanical Engineering, 2016-2018, co-advised with Kate Whitefoot.

Chen, Zihao (Lance) – M.S. Engineering and Public Policy, 2020-pres.

M.S. Independent Research Project

Hsieh, Sandy – *Review of Vehicle Simulation Software* – M.S. Mechanical Engineering, 2006

Chen, Esther – *Review of Multiattribute Utility Theory* – M.S. Mechanical Engineering, 2008

Yuksel, Burak – *Optimal Design and Control of Plug-in Vehicles* – Independent Study, Istanbul Technical University.

Yoon, Hyungchul Paul – *Plug-in Vehicle Optimization for Real-World Driving*, Mechanical Engineering, 2011

Li, Guo – *Optimal Design and Control of Plug-in Vehicles*, Mechanical Engineering, 2012-2013

Pan, Lu – *Impact of Terrain on Life Cycle Implications of Conventional and Electrified Vehicles*, Mechanical Engineering, 2012-2013

Mehta, Darshit – *Optimization of Electric Vehicle Battery and Thermal Management Systems*, Mechanical Engineering, 2015.

Undergraduate Research

Gitomer, Ali – *Review of Automotive Demand Models* – Visiting student, Northwestern University

Hamilton, Andrew – *Study of Consumer Preferences for Hybrid Vehicles* – B.S. Mechanical Engineering, 2008

Hauffe, Richard – *Effects of Battery Weight on Plug-in Hybrid Vehicle Performance* – B.S. Mechanical Engineering, 2008

Lee, Jonghyun – *Review of Environmental Policy for Vehicle Design* – B.S. Mechanical Engineering, 2008

Lewis, Anne Marie – *Optimization of Infrastructure for Ethanol Distribution* – B.S. Mechanical Engineering, 2008

Mikkilineni, Sarat – *Uncertainty in Choice Modeling* – B.S. Mechanical Engineering, 2008

Khwaja, Osman – *Effects of Terrain on Vehicle Efficiency of Electrified Powertrains*, Independent Study, Princeton University, 2011.

Kimball, Paul – *Control Systems for Electrified Vehicles*, 2011-2012

Stabile, Rebecca – *Synthetic Drive Cycle Generation and Fuel Economy Estimation*, 2011-2012.

Finlayson, Andrew -- *Synthetic Drive Cycles and Plug-in Vehicle Simulation*, 2012-2013.

Ph.D. Committee Service

Olson, Jesse –The Collective Potential: Achieving Organizational Potential by Design, Ph.D. Mechanical Engineering, Carnegie Mellon University, 2005 [chair: Jonathan Cagan].

Orsborn, Seth –Quantifying aesthetic preference through statistics applied to an agent-based shape grammar implementation, Ph.D. Mechanical Engineering, Carnegie Mellon University, 2007 [chair: Jonathan Cagan].

Wakeley, Heather – Alternative Transportation Fuels: Infrastructure Requirements and Environmental Impacts for Ethanol and Hydrogen, Ph.D. Civil and Environmental Engineering, Carnegie Mellon University, 2007 [chair: Chris Hendrickson]

Logue, Jennifer – *Characterizing Air Toxics Exposure and Risk in Allegheny County and Evaluating EPA Modeling Tools for Policy Making*, Ph.D. Engineering and Public Policy, Mechanical Engineering, Carnegie Mellon University, 2009 [chair: Allen Robinson].

You, Fengqi – *Mixed Integer Nonlinear Programming Models and Algorithms for Enterprise-Wide Supply Chain Optimization under Uncertainty*, Ph.D. Chemical Engineering, Carnegie Mellon University, 2009 [chair: Ignacio Grossmann].

Hannah, Lindsay – *Combinatory Adaptive Optimization with Multi-Agent Systems* Ph.D., Mechanical Engineering, Carnegie Mellon University, 2009 [chair: Jonathan Cagan].

Hatton, Ross – *Geometric Mechanics of Locomotion and Optimal Coordinate Choice*, Ph.D., Carnegie Mellon University, Mechanical Engineering, 2011 [chair: Howie Choset].

Hassan, Mohd Nor Azman – *GHG Emissions and Costs of Developing Biomass Energy in Malaysia: Implications for Energy Security in the Transportation and Electricity Sectors*, Ph.D. Carnegie Mellon University, Engineering and Public Policy, 2012 [chair: W. Michael Griffin].

Nadadur, Gopal – *Anthropometry-based Sustainable Design for Multiple Global Populations*, Ph.D., The Pennsylvania State University Department of Mechanical and Nuclear Engineering, 2012 [chair: Matthew Parkinson].

Peterson, Scott – *Plug-in Hybrid Electric Vehicles: Battery Degradation, Grid Support, Emissions, and Battery Size Tradeoffs*, Ph.D., Carnegie Mellon University, Engineering and Public Policy, 2012 [chair: Jay Apt].

Venkatesh, Aranya – *Towards Robust Energy Systems Modeling: Examining Uncertainty in Fossil Fuel-Based Life Cycle Assessment Approaches*, Ph.D. Carnegie Mellon University, Civil and Environmental Engineering 2012 [chair: Chris Hendrickson].

Kamath, Ravindra -- *Strategies for Optimization and Heat Integration in Integrated Gasification Combined Cycle Systems*, Ph.D. Chemical Engineering, Carnegie Mellon University, 2012 [chair: Larry Biegler].

Hess, Kacy – *In Situ, Through-Thickness Potential and Current Distribution Measurements in Electrochemical Energy Conversion and Storage Devices*, Ph.D. Mechanical Engineering, Carnegie Mellon University, 2013 [chair: Shawn Litster].

Sylcott, Brian – *Understanding How Consumers Process Product Form and Function and How They Balance Their Preferences for Each*, Ph.D. Mechanical Engineering, Carnegie Mellon University, 2013 [chair: Jonathan Cagan].

Baker, Kyri – *Coordination of Resources across Areas for the Integration of Renewable Generation: Operation, Sizing, and Siting of Storage Devices*, Ph.D. Electrical and Computer Engineering, Carnegie Mellon University, 2014 [chair: Gabriela Hug-Glanzmann].

Jenn, Alan – *Analysis of Transportation Policies: Regulations and Incentives in the United States*, Ph.D. Engineering and Public Policy, Carnegie Mellon University, 2014 [chair. Inês Azevedo].

Heo, Jinhyok – *Evaluation of Air Quality Impacts on Society: Methods and Application*, Ph.D. Engineering and Public Policy, Carnegie Mellon University, 2014 [chair: Peter Adams].

Dowling, Alex -- *Equation Oriented Flowsheet Optimization for Advanced Energy Processes*, Ph.D. Chemical Engineering, Carnegie Mellon University, 2015 [chair: Larry Biegler].

Zhang, Qi – *Enterprise-wide Optimization for Industrial Demand Side Management*, Ph.D. Chemical Engineering, Carnegie Mellon University, 2016 [chair: Ignacio Grossmann].

Seki, Stephanie – *Evaluating the Economic, Environmental and Policy Impacts of Ethanol as a Transportation Fuel in Pennsylvania*, Ph.D. Engineering and Public Policy, Carnegie Mellon University, 2016 [chairs: Chris Hendrickson and W. Michael Griffin].

Tong, Fan – *The Good, the Bad, and the Ugly: Economic and Environmental Implications of using Natural Gas to Power On-Road Vehicles in the United States*, Ph.D. Engineering and Public Policy, Carnegie Mellon University, 2016 [chairs: Paulina Jaramillo and Inês Azevedo].

Mersky, Avi – *Environmental and Policy Implications of Vehicle Automation and Electrification*, Civil and Environmental Engineering, Carnegie Mellon University, 2017 [chair: Constantine Samaras].

Li, Zhongju (Hugh) – *Urban Aerosol: Spatiotemporal Variation and Source Characterization*, Mechanical Engineering, Carnegie Mellon University, 2018 [chair: Albert Presto].

Ciez, Rebecca – *Battery Energy Storage for Maturing Markets: Performance, Cost, Perceptions, and Environmental Impacts*, Ph.D., Engineering & Public Policy, Carnegie Mellon University, 2018 [Chair: Jay Whitacre].

Chen, Mo – *Vehicle and Vehicle-related Policy Analysis in China*, Engineering and Public Policy, Carnegie Mellon University (current) [chair: Paul Fischbeck].

Styler, Alex – *Learning, Prediction, and Optimization for Hybrid Vehicle Energy Management*, School of Computer Science, Carnegie Mellon University (current) [chair: Illah Nourbakhsh].

Tee, Chin Yen – *Market Design and Risk Management for Flexibility in the Future Electric Transmission System*, Engineering and Public Policy, Carnegie Mellon University, 2017 [chair: Marija Ilic].

Chen, Qi – *Computational Tools for Process Synthesis*, Chemical Engineering, Carnegie Mellon University, 2020 [chair: Ignacio Grossmann].

Lu, Quanyang – *Mobile Source Emission Profiles and the Social Cost of Air Pollution*, Mechanical Engineering, Carnegie Mellon University, 2020 [chair: Robinson].

He, Guannan – *Storage for Low-Carbon Energy System: Decisions, Economics, Business Model, and Policy*, Engineering and Public Policy, Carnegie Mellon University, 2019 [chair: Jay Whitacre].

Farquharson, DeVynne – *Sustainable Energy Transitions in Sub-Saharan Africa: Impacts on Air Quality, Economics, and Fuel Consumption*, Engineering and Public Policy, Carnegie Mellon University, 2019 [chair: Jaramillo].

Braaten, Jonathan – *Understanding Catalyst Layer Morphology and Degradation and their Impact on Critical Oxygen Transport in PEMFC Cathodes*, Mechanical Engineering, Carnegie Mellon, 2021 [chair: Litster].

Gowharji, Waleed – Mechanical Engineering, Carnegie Mellon (current) [chair: Kate Whitefoot]

Mohan, Aniruddh – Mechanical Engineering, Carnegie Mellon (current) [chair: Parth Vaishnav and Venkat Viswanathan]

Choi, Paul – (TBD) Mechanical Engineering, Carnegie Mellon (current) [chair: Shawn Litster]

TEACHING EXPERIENCE

19-668 **Electric Vehicles: Technology, Economics, Environment and Policy** (2021-pres)

In this course, students read academic literature, government documents, and popular press to develop a broad understanding of the technology, economic, environmental and policy dimensions of electric vehicles. Topics include (1) Technology: Battery technology, design, application, degradation and innovation; electric vehicle technologies and designs; the electric power grid; (2) Economics: cost; consumer behavior; infrastructure; electricity dispatch; automotive externalities; the Gruenspecht effect; (3) Environment: life cycle assessment; air pollution; greenhouse gas emissions; marginal grid emission factors; renewables; vehicle to grid; hydrogen; (4) Policy: effectiveness, efficiency, uncertainty and equity; short-run versus long-run effects; fleet standards; incentives; mandates; policy interactions; intellectual property; and policies in the US, China, EU, Japan, and local jurisdictions. Fundamentals covered at an introductory level to support readings include time value of money, economies of scale, social welfare analysis, externalities, valuation of reduced mortality risk; choice modeling, regression, life cycle assessment, and other topics.

24-785 **Engineering Optimization** (2010-pres)

This course introduces students to 1) the process of formally representing an engineering design or decision-making problem as a mathematical problem and 2) the theory and numerical methods needed to understand and solve the mathematical problem. Theoretical topics focus on constrained nonlinear programming, including necessary and sufficient conditions for local and global optimality and numerical methods for solving nonlinear optimization problems. Additional topics such as linear programming, mixed integer programming, global optimization, and stochastic methods are briefly introduced. Model construction and interpretation are explored with metamodeling and model reformulation techniques, study of model boundedness, constraint activity, and sensitivity analysis. Matlab is used in homework assignments for visualization and algorithm development, and students apply theory and methods to a topic of interest in a course project.

19-670 / 24-680 **Quantitative Entrepreneurship: Analysis for New Technology Commercialization** (2008-pres)

Formerly 19-484/24-484/19-784/24-784 Decision Tools for Engineering Design and Entrepreneurship; Co-instructors: Prof. Erica Fuchs, Prof. Kate Whitefoot

This course provides engineers with a multidisciplinary mathematical foundation for integrated modeling of engineering design and enterprise planning decisions in an uncertain, competitive market. Topics include economics in product design, manufacturing and operations modeling and accounting, consumer choice modeling, survey design, conjoint analysis, decision-tree analysis, optimization, model integration, and professional communication skills. Students will apply theory and methods to a team project for a new product or emerging technology of their choice, developing a business plan to defend technical and economic competitiveness. Students may select emerging technologies from research at Carnegie Mellon for study in the course, and in some years venture capitalists and other industry leaders may take part in critiquing student projects. This course assumes fluency with calculus and some prior programming experience.

24-441 / 24-442 **Engineering Design II: Conceptualization and Realization**, Carnegie Mellon University (2006-pres)

In this course, students gain hands-on, practical experience applying engineering principles, theories, thought processes, and problem-solving approaches to the design and prototyping of a physical product. Students develop skills for working in teams, working with open-ended problems, and making appropriate engineering assumptions. Students are expected to research the topic area, identify opportunities and design criteria, generate creative concepts, synthesize detailed design of the concept, analyze the design on a number of criteria to make improvements, and prototype and communicate the final solution.

24-789C **Quantitative Methods for Product Design and Development**, Carnegie Mellon University (2006)

This course provides a multidisciplinary mathematical foundation for integrated modeling in product design and development. In this course, students learn introductory theory and methods for building and solving optimization models integrating producer, consumer, competitor, regulator, and designer perspectives. Topics include optimization methods with a focus on nonlinear programming, choice modeling, conjoint analysis, game theory, policy analysis, decomposition and model integration. Students apply methods to a team project and engage in independent research to deepen knowledge on a relevant topic of interest.

ENGR490 **Engineering for Community**, University of Michigan (2003-2004)

Worked to co-design, develop, and implement a new interdisciplinary engineering course focusing on learning through experience and field work, international and local community development, social and cultural awareness, sustainability, appropriate technology, and communication skills.

Graduate Student Instruction Mentor, University of Michigan (2003-2004)

University of Michigan Center for Research on Learning and Teaching

Trained and assisted graduate student instructors, facilitated student feedback on teaching and provided teaching observations and evaluations.

ME 499/599 Analytical Product Design, University of Michigan (2003, 2004)

Helped to develop and implement a new interdisciplinary course on model-based product development. Gave lecturers, provided student support, and developed computer tools for students.

ME 555 Design Optimization, University of Michigan (2003)

Acted as a course aid for the graduate-level course on design optimization. Developed new material and gave lectures and demonstrations.

Rackham-CRLT Seminar on College Teaching, University of Michigan (2003)

Participated in the selective Center for Research on Learning and Teaching Preparing Future Faculty Seminar on College Teaching to sharpen teaching philosophy, learn about the structure of higher education institutions in the United States, and develop teaching skills.

Multicultural Classroom Facilitation Training, University of Michigan (2003)

Participated in a training course emphasizing teaching through dialogue and focusing on issues of multiculturalism, diversity, and social and cultural awareness.

Detroit Area Pre-College Engineering Program, University of Michigan (2002-2003)

Exposed middle-school students from minority and low-income areas to engineering by providing hands-on examples and activities in order to improve accessibility of the field. Position: instructor.

Michigan Mentor Program, University of Michigan (2000-2002)

Worked with two middle school students one-on-one to provide exposure to the engineering disciplines and work with them to explore career possibilities in engineering and beyond.

ME 450 Design and Manufacturing III, University of Michigan (2000-2001)

Assisted in teaching and advising the capstone mechanical engineering design course. Developed new course material and restructured the syllabus. Initiated and supported interdisciplinary student coursework and project interaction with the University Of Michigan School of Art and Design and the Parsons School of Design. Developed an interactive course web portal to support distance collaboration.

Tutor, Carnegie Mellon University (1997)

Tutored undergraduates in programming the C++ language.

CONSULTING EXPERIENCE

New York State Energy Research and Development Authority (NSERDA) (2014-2017)

With Industrial Economics, Inc.

INDUSTRY EXPERIENCE

Research Engineer, Intern

Xerox – The Document Company, Rochester, NY (summer 1999)

Designed and implemented improvements to a distributed embedded digital control system for paper path handling.

Design Engineer, Intern

General Motors, Warren, MI (summer 1998)

Worked with a multidisciplinary team including engineering, industrial design, and sculpture to design and prototype a future concept vehicle with engineering documentation to show concept feasibility.

Reliability Engineer, Intern

General Motors, Warren, MI (summer 1997)

Developed and implemented a procedure to quantify the reliability of commercial components of machinery and equipment in the assembly plant environment.

Designer

Linear Systems Corporation, Rochester, MI (1994-1996)

Designed automotive tooling. Trained employees in AutoCAD. Developed new CAD tools.

ORGANIZATIONAL LEADERSHIP AND MEMBERSHIP

Leadership

Director, Vehicle Electrification Group (since 2012)

Co-Director, Vehicle Electrification Group (2009-2012)

Chair, EPP Master of Science Program Committee (2020-pres)

Chair, EPP Communications and Diversity Committee (2017-2018)

Acting Co-Director, Master in Product Development program (2008-2009)

Director, Design Decisions Laboratory, Carnegie Mellon University (since 2005)

Chair, Publicity and Newsletter Committee, ASME Design Engineering Division (2007-2009)

Membership

Member, Center for Climate and Energy Decision Making, Carnegie Mellon University (since 2011)

Member, Electricity Industry Center, Carnegie Mellon University (since 2011)

Member, Center for Product Strategy and Innovation, Carnegie Mellon University (2008-2010)

Member, Green Design Institute, Carnegie Mellon University (since 2006)

Member, ASME: American Society of Mechanical Engineers (since 1997)

Member, INFORMS: Institute for Operations Research and the Management Sciences (since 2005)

Member, TRB: National Academies Transportation Research Board Alterative Transportation Fuels and Technologies Committee (2014-present)

Graduate Student Activities

Engineers Without Borders / BLUElab, University of Michigan, Education Chair (2003-2005)

Graduate Student Mentor (2003-2004)

Amnesty International Student Group on Economic and Social Rights (2003-2004)

Public Service Announcement Director, WCBN-FM Ann Arbor (2002-2004)

University of Michigan Graduate Student Symposium, Design and Manufacturing Chair (2001)

Interdisciplinary Antilium Education and Research Collaboration Initiative (2001-2005)

New Foreign Graduate Student Mentor (2000-2002)

New Graduate Student Recruiter (2000)

RESEARCH GRANTS AND AWARDS

Principal Investigator: (total $2.6M)

[1] Mobility21, “Ridehailing Service Equity in Normal and Rare Conditions,” Nov 2020.

[2] ATLAS Moonshot, “Autonomous Taxis: Understanding and Improving Sustainability and Equity,” Aug 2020.

[3] U.S. Department of Energy “Dynamic Effects of Technology-Forcing ZEV Policy under Vehicle Fleet Standards,” Aug 2019

[4] National Bureau of Economic Research, “Effects of On-Demand Ridesourcing on U.S. Vehicle Ownership, Travel Patterns, and Energy Use Externalities” March 2018.

[5] Steinbrenner Institute for Environmental Education and Research, “How Do Shared Mobility and Autonomous Taxis Affect Energy Consumption, Vehicle Use, and Emissions of Greenhouse Gases and Criteria Air Pollutants?” August 2017.

[6] Scott Institute for Energy Innovation, “How Do Shared Mobility and Autonomous Taxis Affect Energy Consumption, Vehicle Use, and Greenhouse Gas and Criteria Pollution Emissions?” January 2017.

[7] Toyota Motor Corporation, “Advanced Vehicle Research,” January, 2015.

[8] Toyota Motor Corporation, “Vehicle Electrification Research and Policy,” August 2013.

[9] Toyota Motor Corporation, “Autonomous Vehicle Research,” [co-PI Chris Hendrickson] June 2013.

[10] Toyota Motor Corporation, “Advanced Vehicle Research,” October 2012.

[11] Toyota Motor Corporation, “PHEV Research,” [co-PI Jay Whitacre], September 2011.

[12] Ford Motor Company, “Electrified Vehicles in China: Identifying Consumer Preferences and Key Factors that Impact Adoption,” Sept 2011 – Aug 2014.

[13] Toyota Motor Corporation, “Life Cycle Cost and Environmental Assessment of Plug-in Vehicles,” [co-PIs Jay Whitacre, Constantine Samaras], August 2010.

[14] Toyota Motor Corporation, “Systems Analysis of Plug-in Hybrid Electric Vehicles,” [co-PIs Jay Whitacre, Constantine Samaras], April 2009.

[15] National Science Foundation, CAREER Award, “Driving Design: Modeling the Influence of Market Forces and Public Policy on Engineering Design Decision-Making,” Aug 2008 – Aug 2013.

[16] Ford Motor Company, “Engineering and Market Simulation for Optimal Product Planning under Environmental Regulation,” Aug 2008 – Aug 2011.

[17] Carnegie Mellon Institute for Entrepreneurship, Innovation and Technology course development grant for “Quantitative Methods for Product Design and Development,” Aug 2007 – July 2012.

[18] Pennsylvania Infrastructure Technology Alliance, “A Systems Decomposition Approach for Optimization of Product Families to Balance Market and Engineering Needs,” Jan – Dec 2007 [Co-PIs Peter Boatwright, Tim Simpson].

[19] Pennsylvania Infrastructure Technology Alliance, “Hierarchical Design Optimization of Complex Systems,” Jan – Dec 2006 [Co-PIs Jon Cagan, Zhaosong Lu].

Co-Investigator (total $15M)

[20] Center for Applied Environmental Law and Policy, “Changing Consumer Preferences for EVs Over Time,” 2020.

[21] U.S. Department of Energy, "Understanding and Improving Energy Efficiency of Regional Mobility Systems Leveraging System-Level Data," 2018.

[22] U.S. Department of Energy, "Drones, Delivery Robots, Driverless Cars, and Intelligent Curbs for Increasing Energy Productivity of First/Last Mile Goods Movement," 2018.

[23] Carnegie Mellon University, "Carnegie Mellon Equipment Grant Proposal," 2017.

[24] Electric Power Research Institute, "Estimating Consumer Preferences for Diverse Electric Services," 2016.

[25] Carnegie Mellon University College of Engineering, "Workshop on Techno-Economic Assessment Methods for Energy Technologies," 2016.

[26] Scott Institute for Energy Innovation, "Techno-Economic Assessment Methods for Energy Technologies," 2016.

[27] Environmental Protection Agency Air, Climate, and Energy (ACE) Center, "Center for Air, Climate, and Energy Solutions (CACES)", 2015-2020.

[28] Carnegie Mellon University Transportation Center, "Evaluating the Opportunities for Cost Savings and Environmental Benefits of Coupling Solar Energy and Electric Vehicles in City of Pittsburgh Municipal Operations," 2015.

[29] Fuels Institute "Comparative Analysis of the Economic and Environmental Impacts of CNG and LNG for the Transportation Sector," 2014-2015.

[30] Fuel Freedom Foundation "Assessment of Comparative Economic and Environmental Impacts of Alternative Light Duty Vehicle Liquid Fuels Produced from Natural Gas," 2014-2015.

[31] Carnegie Mellon Metro 21 "Evaluating the Opportunities for Cost Savings and Environmental Benefits of Coupling Solar Energy and Electric Vehicles in City of Pittsburgh Municipal Operations," 2014-2015 [PI: Constantine Samaras].

[32] Research for Advanced Manufacturing in Pennsylvania "Manufacturing Modeling Tools for Domestic Energy Storage Production: Process-Based Cost Modeling," 2012-2014 [PI: Erica Fuchs].

[33] Carnegie Institute of Technology "Institutionalizing and Disseminating Engineering Entrepreneurship," 2012-2013 [PI: Erica Fuchs].

[34] National Science Foundation, SciSIP Program (2011) "GOALI: Think Globally Act Locally – China and the Future of Energy-Saving Vehicle Technologies," Sept 2011 – Aug 2014 [PI: Erica Fuchs].

[35] Mellon Foundation award for "Course Instructor Outreach to Carnegie Mellon's Center for Technology Transfer," 2008-2009 [PI: Erica Fuchs].

[36] National Science Foundation, MUSES Program "Material Use, Infrastructure Change, and Environmental Impacts for Alternative Fuels and Vehicles," Sept 2006 – Aug 2011 [PI: Lester Lave. Co-PIs: Chris Hendrickson, H. Scott Matthews, W. Michael Griffin].

[37] United States Environmental Protection Agency P3 Award People Prosperity and the Planet Award for project "AWARE: A Step Toward Building a Sustainable Economy by Informing Consumer Purchasing Decisions at the Point of Sale," Sept 2004 – May 2005 [PI: Steven Skerlos, co-investigator W. Ross Morrow].

Student Awards (total $0.3M)

[38] Dwight David Eisenhower Transportation Fellowship "How to Autonomy, Connectivity, and the Sharing Economy Affect Passenger Travel? Informing the Technical and Policy Framework for a New Mobility Future" student: Ward 2017.

[39] Link Foundation “Environmental Implications of Consumer Preferences and Policy Incentives for Plug-in Vehicles in China and the U.S.” student: Helveston 2014-2015.

[40] National Science Foundation Graduate Research Fellowship "Can Controlled Charging of Electric Vehicles Reduce the Economic and Environmental Implications of Integrating Wind Power into the Electricity Grid?" student: Allison Weis, 2011, June 2012 - May 2015.

[41] National Science Foundation Graduate Research Fellowship “How Does Energy Policy Affect Vehicle Design?” student: Elizabeth Traut, 2009, June 2009 – May 2012.

[42] Steinbrenner Institute for Environmental Education and Research “How Does Energy Policy Affect Vehicle Design?” student: Elizabeth Traut, August 2009 – July 2010.

HONORS AND AWARDS

Faculty

Steven J. Fenves Award for Systems Research, Carnegie Mellon University (2018)

Thar Energy Design Award, American Society of Mechanical Engineers (2016)

Philip L. Dowd Fellowship Award, College of Engineering, Carnegie Mellon University (2015)

Best Article Award, European Marketing Academy, International Journal of Research in Marketing, Best Article in 2011

Best Course, awarded by the Carnegie Mellon Mechanical Engineering Class of 2010

American Society of Mechanical Engineers, Design Automation Outstanding Young Investigator Award (2009)

George Tallman Ladd Research Award for outstanding research and professional accomplishments and potential (2008)

Best Use of Technology in the Classroom, awarded by the Carnegie Mellon Mechanical Engineering Class of 2006

American Society of Mechanical Engineers Design Automation Conference Best Paper Award (2005)

Student

NSF Engineering Research Center for Reconfigurable Manufacturing Systems Ph.D. Student of the Year Award (2005)

Elaine Harden Award for Outstanding Leadership in College, University and Community Activities, (2005) – University of Michigan BLUElab Executive Committee

Martin Luther King Jr. Spirit Award for co-development of new Engineering for Community course (2004) – University of Michigan

Michigan Teaching Fellow (2003) – University of Michigan Horace H. Rackham School of Graduate Studies and the Center for Research on Learning and Teaching

University of Michigan Mechanical Engineering Graduate Student Council Second Place Award for Research Poster Competition at the Graduate Student Symposium (2003)

Rackham Interdisciplinary Institute Fellowship (2001-2002)

Devlieg Fellowship and Scholarship (2000)

Engineering Graduate Fellowship (1999)

Graduated first in the ME class of 1999 at Carnegie Mellon with University Honors

Motorola Second Place Research Award for Sigma Xi Undergraduate Research Symposium (1999)

Carnegie Institute of Technology Third Place Research Award for Sigma Xi Undergraduate Research Symposium (1999)

Bennett Award for Academic Achievement (1999)

Department Research Honors, Carnegie Mellon Mechanical Engineering (1999)

Student Leadership Award, Carnegie Mellon University (1999)

ACADEMIC SERVICE (since 2005)

Editor:

ASME Design Engineering Division Newsletter Editor (2006-2009)

Concurrent Engineering: Research and Applications, An International Journal (guest editor, Special Issue on Managing Modularity and Commonality in Product and Process Development, 2005-2006)

Reviewer:

ACS Omega

AIAA Journal

AMA American Marketing Association Conference

Applied Energy

ASME Journal of Mechanical Design

ASME Design Engineering Technical Conferences

Concurrent Engineering - Research and Applications

Design Science

Energies

Energy Journal

Energy Policy

Engineering Optimization

Environmental Research Letters

Environmental Science and Technology

IEEE Spectrum

IEEE Transactions on Automation Science and Engineering

IEEE Transactions on Engineering Management

IEEE Transactions on Power Systems

IEEE Transactions on Smart Grid

International Journal of Hydrogen Energy

International Journal of Information Technology and Decision Making

International Journal of Manufacturing Technology and Management

International Journal of Product Development

Journal of Cleaner Production

Journal of Intelligent Manufacturing

Marketing Science (INFORMS)

National Petroleum Council

National Renewable Energy Laboratory

National Research Council of the National Academies

National Science Foundation

Nature Energy

Proceedings of the National Academy of Sciences of the United States of America

Research in Engineering Design

Science Advances

Structural and Multidisciplinary Optimization

Sustainable Transportation

Transport Policy

Transportation Research Board

Transportation Research Part A: Policy and Practice

Transportation Research Part D: Transport and Environment

Transportation Science

Union of Concerned Scientists

World Electric Vehicle Journal

Conference Session Organizer / Review Coordinator:

ASME International Design Engineering Technical Conferences

INFORMS Annual Meeting

Transportation Research Board Annual Meeting

Conference Session Chair:

ASME Design Engineering Technical Conferences

INFORMS Annual Meeting

Transportation Research Board Annual Meeting

Outreach and Public Service:

Committee on Current Methods for Life Cycle Analysis of Low-Carbon Transportation Fuels in the United States, The National Academies of Science, Engineering and Medicine (2021-pres)

Testimony at public hearing of Environmental Protection Agency and National Highway Traffic Safety Administration on proposed changes to the federal light-duty vehicle fuel economy and greenhouse gas emissions standards (2018)

Commentary on Pennsylvania House Bill 1446 for Office of PA Representative Dan Frankel (2018)

Policy Briefing, U.S. House of Representatives (2017)

Policy Briefing, National Governors Association (2017)

Policy Briefing, U.S. Department of Transportation (2017)

Policy Briefing, Office of U.S. Senator Toomey (2017)

Policy Briefing, National Resources Defense Council (2016)

Policy Briefing, National Renewable Energy Laboratory (2016)

Policy Briefing, Environmental Protection Agency (2016)

Policy Briefing: California Energy Commission (2015)

Policy Briefing: California Air Resources Board (2015)

Policy Briefing: California State Senate Transportation Committee (2015)

Policy Briefing: California State Assembly Transportation Committee (2015)

Policy Briefing: Office of State Senator Fran Pavley (2015)

Policy Briefing: California State Assembly Natural Resources Committee (2015)

Policy Briefing, Union of Concerned Scientists (2015)

Policy Briefing, U.S. Congressional Budget Office (2012)

Policy Briefing, U.S. Congressional Research Service (2012)

Policy Briefing, U.S. Senate Energy and Natural Resources Committee (2012)

Policy Briefing, U.S. Senate Commerce, Science and Transportation Committee (2012)

Policy Briefing, Office of U.S. Representative Levin (2012)

Policy Briefing, National Academy of Engineering, Maxine Savitz, Vice President (2012)

National Petroleum Council study on Future Transportation Fuels, Electricity Subgroup (2010-2012)

Policy Briefing, U.S. House of Representatives Energy and Commerce Committee (2009)

Policy Briefing, U.S. House of Representatives Committee on Science and Technology (2009)

Policy Briefing, U.S. House of Representatives Select Committee on Energy Independence and Global Warming (2009)

Policy Briefing, U.S. Congressional Research Service (2009)

Policy Briefing, Office of U.S. Senator Specter (2009)

Policy Briefing, Office of U.S. Representative Markey (2009)

Green Design Apprenticeship, 6 day course for high-school students (2007-present)

Society of Women Engineers High School Day Workshop (2005-2008)

Society Service:

Transportation Research Board of the National Academies, Alternative Transportation Fuels and Technologies Committee (member since 2014, friend since 2013)

Transportation Research Board of the National Academies, Transportation Energy Committee (friend since 2013)

ASME Design Engineering Division, Chair: Publicity and Newsletter Committee (2007-2009)

ASME Design Automation Committee (since 2005)

University Service:

Engineering and Public Policy MS Program Committee Chair (2020-pres)

Engineering and Public Policy Strategic Review Committee (2019-2020)

Engineering and Public Policy Department Head Search Committee (2019-2020)

Engineering and Public Policy Communications and Diversity Committee (2016-2018)

Mechanical Engineering Awards Committee (2019-pres)

Mechanical Engineering Undergraduate Education Committee (2016-pres)

Engineering and Public Policy Communications and Diversity Committee, Chair (2016-2017)

Carnegie Institute of Technology Ad Hoc Promotion and Tenure Committee (2014-2015)

Chair, Carnegie Mellon Mechanical Engineering Communications Committee (2013-2014)

Department Head Search Committee, Engineering and Public Policy (2013-2014)

Chair, Carnegie Mellon Engineering and Public Policy Graduate Education Committee (since 2013)

Department Head Search Committee, Mechanical Engineering (2012)

Acting co-director, Master in Product Development program, (2008-2009)

Mechanical Engineering Curriculum Assessment Committee (since 2010)

Mechanical Engineering Undergraduate Education Committee (2006-2011)

Mechanical Engineering Library Committee (2006-2008)

Engineering and Public Policy Qualifying Examination Service (since 2006)

Mechanical Engineering Qualifying Examination Service (since 2005)

Mechanical Engineering Seminar Series Committee (2005-2006)

INVITED SEMINARS

[1] Uber and Lyft Implications: Vehicle Ownership, Transit, Electrification, Air Emissions, Traffic Externalities and Equity, CMU Smart Mobility Connection, March 2021 (online).

[2] Externalities of Policy-Induced Scrappage: The Case of Automotive Regulations, U.S. Environmental Protection Agency, May 2021 (online).

[3] Evolving Consumer Preferences for Electric Vehicles, U.S. Environmental Protection Agency, March 2021 (online).

[4] Alternative-Fuel-Vehicle Policy Interactions Increase U.S. GHG Emissions, Industry Studies Association, June 2020 (online).

[5] Effects of On-Demand Ridesourcing on U.S. Vehicle Ownership, Travel, Energy, and Environmental Outcomes, National Bureau of Economic Research, 2019, Washington D.C.

[6] U.S. Light-Duty Vehicle Fleet Efficiency and Greenhouse Gas Emissions Policy -- Past, Present, and Future, Webinar provided by Carnegie Mellon Transportation Electrification Group, 2018.

[7] Effects of On-Demand Ridesourcing on U.S. Vehicle Ownership, Travel Patterns, and Energy Use Externalities, National Bureau of Economic Research, 2018, Washington, D.C.

[8] Automobile Air Emissions and the Transition to Electric Powertrain Technology, Carnegie Mellon Department of Mechanical Engineering, Mar 23, 2018, Pittsburgh, PA.

[9] Carnegie Mellon Vehicle Electrification Group, Department of Energy Vehicle Technologies Office Meeting, Oct 25, 2017, Pittsburgh, PA.

[10] Carnegie Mellon Vehicle Electrification Group, Federal Highway Administration Meeting, Sept 25, 2017, Pittsburgh, PA.

[11] Carnegie Mellon Vehicle Electrification Group, National Renewable Energy Laboratory Smart PGH Meeting, April 19, 2017, Pittsburgh, PA.

[12] Implications of Utility-Controlled Charging for Electric Vehicle Cost and Emissions, Vehicle Grid Integration Workshop, Transportation Research Board Annual Meeting, Jan 8, 2017, Washington, D.C.

[13] Techno-Economic Analysis for Differentiated Products, Institute for Techno-Economic Assessment Methods, Carnegie Mellon University, Nov 18, 2016, Pittsburgh, PA.

[14] Electric Vehicle Adoption Potential in the United States, University of California, Davis, Apr 12, 2016, Davis, CA.

[15] Electric Vehicles: Benefits, Costs, and Policies in the United States, National Resources Defense Council, Apr 11, 2016, San Francisco, CA.

[16] Upstream Emissions from Electric Vehicle Charging, UN Economic Commission for Europe EVE Working Group, Apr 11, 2016, delivered remotely to China.

[17] Electric Vehicles: Benefits, Costs, and Policies in the United States, Stanford University Precourt Institute for Energy, Apr 8, 2016, Stanford, CA.

[18] Alternative Fuel Vehicle Adoption Increases U.S. Fleet Gasoline Consumption and Greenhouse Gas Emissions under Federal Corporate Average Fuel Economy and Fleet Greenhouse Gas Emission Policy, King Abdullah Petroleum Studies and Research Center Workshop, April 1, 2016, San Francisco, CA.

[19] Electric Vehicles: Benefits, Costs, and Policies in the United States, Energy Institute at Haas, University of California, Berkeley, March 31, 2016, Berkeley, CA.

[20] Electric Vehicles: Benefits, Costs, and Policies in the United States, Lawrence Berkeley National Laboratory, Mar 29, 2016, Berkeley, CA.

[21] Electric Vehicles: Benefits, Costs, and Policies in the United States, Renewable and Appropriate Energy Laboratory, Energy Resources Group, University of California, Berkeley, Mar 16, 2016, Berkeley, CA.

[22] Electric Vehicles: Benefits, Costs, and Policies in the United States, Ford Motor Company, Mar 3, 2016, Palo Alto, CA.

[23] Electric Vehicle Adoption Potential in the United States, National Renewable Energy Laboratory, Feb 2, 2016, Golden, CO.

[24] Electric Vehicles: Benefits, Costs, and Policies in the United States, National Renewable Energy Laboratory, Feb 2, 2016, Golden, CO.

[25] Electric Vehicles: Benefits, Costs, Policies, and Adoption Potential in the United States, Environmental Protection Agency, Office of Transportation and Air Quality, Jan 20, 2016, Ann Arbor, MI.

[26] Electric Vehicles: Benefits, Costs, Policies, and Adoption Potential in the United States, Centro para a Excelência e Inovação na Indústria Automóvel, Dec 15, 2015, Matosinhos, Portugal.

[27] Electric Vehicles: Benefits, Costs, Policies, and Adoption Potential in the United States, Instituto Superior Téchnico, Universidade de Lisboa, Dec 11, 2015, Lisbon, Portugal.

[28] Electric Vehicles: Benefits, Costs, and Adoption Potential in the United States, California Energy Commission, June 2015, Sacramento, CA.

[29] Electric Vehicles: Benefits, Costs, and Adoption Potential in the United States, California Air Resources Board, June 2015, Sacramento, CA.

[30] Electric Vehicles: Benefits, Costs, and Adoption Potential in the United States, University of California, Davis, June 2015, Davis, CA.

[31] Electric Vehicles: Benefits, Costs, and Adoption Potential in the United States, Union of Concerned Scientists, June 2015, Oakland, CA.

[32] Carnegie Mellon Vehicle Electrification Group, Toyota Motor Sales, September 12, 2014, Torrance, CA.

[33] Vehicle Automation: Implications for Advanced Vehicle Energy Technologies, University of Michigan Transportation Research Institute Global Symposium (invited by Jacob Ward, US DOE), April 23, 2014, Ann Arbor, MI.

[34] Plug-in Vehicle Life Cycle Benefits and Costs: Implications and Strategies, University of Illinois at Urbana-Champaign, February 28, 2013, Champaign, IL.

[35] The Costs and Benefits of Plug-in Vehicles: How Much Can We Control? University of California, San Diego, February 22, 2013, San Diego, CA.

[36] Air Emissions and Oil Displacement Benefits from Plug-in Vehicles, Society of Automotive Engineers Hybrid and Electric Vehicle Symposium, February 20, 2013, Anaheim, CA.

[37] Effect of Location and Driving Conditions on Plug-in Vehicle Benefits, Transportation Research Board of the National Academies, January 13, 2013, Washington D.C.

[38] Quantifying Plug-in Vehicle Benefits, Argonne National Laboratory, Aug 17, 2012, Argonne, IL.

[39] Thoughts on the Field of Design for Market Systems, Northwestern University, Aug 16, 2012, Evanston, IL.

[40] Are Plug-in Vehicles Worth the Cost? Valuing Air Emissions and Oil Displacement Benefits in the U.S., March 14, 2012 Toyota Motor North America, Washington, DC.

[41] Are Plug-in Vehicles Worth the Cost? Valuing Air Emissions and Oil Displacement Benefits in the U.S., Sept 2011, Cambridge University, U.K.

[42] Life Cycle Cost, Air Emissions, and Oil Displacement Potential of Plug-in Vehicles, Ford Motor Company, July 2011, Dearborn, MI.

[43] On the Life Cycle Implications of Plug-in Hybrid Electric Vehicles, University of California Berkeley, Oct 22, 2010, Berkeley, CA.

[44] On the Life Cycle Implications of Plug-in Hybrid Electric Vehicles, Stanford University, Precourt Energy Efficiency Center, Oct 21, 2010, Stanford, CA.

[45] Product Design in Strategic Firm Decision-Making, Stanford Graduate School of Business, Operations, Information and Technology Group, Oct 20, 2010, Stanford, CA.

[46] On the Life Cycle Implications of Plug-in Hybrid Electric Vehicles, University of California Davis, ITS-STEPS Seminar, Oct 19, 2010, Davis, CA.

[47] Do More Batteries Make a Plug-in Better? Economic and Environmental Analysis of Plug-in Hybrid Electric Vehicles, Society of Automotive Engineers Government-Industry Meeting, January 28, 2010, Washington, D.C.

[48] Market Forces and Public Policy in Engineering Systems Optimization, Massachusetts Institute of Technology, Engineering Systems Division, June 12, 2009, Boston, MA.

[49] Design for Market Systems: Integrating Social, Economic, and Physical Sciences to Engineer Product Success, University of Maryland – College Park, Design and Reliability of Systems Division, January 14, 2009, College Park, MD.

[50] Design for Market Systems: Integrating Social, Economic, and Physical Sciences to Engineer Product Success, The Pennsylvania State University, Industrial and Manufacturing Engineering, October 16, 2008, State College, PA.

[51] Driving Design: Modeling Market Forces and Public Policy in Vehicle Design, State University of New York at Buffalo, Mechanical and Aerospace Engineering, April 10, 2008, Buffalo, NY.

[52] Should Designers Worry about Market Structure?, The Pennsylvania State University, Engineering Design, April 4, 2008, State College, PA.

[53] Modeling Energy Policy and Consumer Choice in Vehicle Design Optimization, Ford Motor Company, Systems Analytics and Environmental Sciences, July 25, 2007, Detroit, MI.

[54] Realizable Product Line Optimization: Coordinating Product Positioning and Design for Heterogeneous Markets, Tepper School of Business, Carnegie Mellon University, Feb. 24, 2006, Pittsburgh, PA.

[55] A Model for Studying the Impact of Fuel Economy and Emission Policy on Profit-Driven Vehicle Design Decisions in a Competitive Market, Green Design Institute, Carnegie Mellon University, Oct. 20, 2005, Pittsburgh, PA.

[56] Preference Coordination in Engineering Design Decision-Making, Mechanical Engineering, Northwestern University, March 31, 2005, Evanston, IL.

[57] Preference Coordination in Engineering Design Decision-Making, General Motors Research and Development Seminar, Oct. 27, 2004, Detroit, MI.

[58] Individual, Social and Economic Preference in Engineering Design Decision-Making, Eindhoven University of Technology, April 22, 2004, Eindhoven, The Netherlands.

[59] Automotive Design and Environmental Policy in the US Market, Delft University of Technology, April 21, 2004, Delft, The Netherlands.

[60] Coordination of Preferences Using Hierarchical Optimization of Complex Systems, Ecole Centrale de Nantes, April 19, 2004, Nantes, France.

[61] Automotive Design and Environmental Policy in the US Market, Technischen Universität Berlin, April 8, 2004, Berlin, Germany.

PROFESSIONAL PRESENTATIONS

[62] Externalities of Policy-Induced Scrappage: The Case of Automotive Regulations, Transportation Research Board Annual Meeting, Jan 2021 (with C. Forsythe)

[63] The Dynamic Costs and Benefits of Technology-Forcing Policy Nested in a Broader Performance Standard: The Case of ZEV and CAFE, Transportation Research Board Annual Meeting, Jan 2021 (with A. Yip)

[64] Effects of Air Emissions Externalities on Optimal Ride-Hailing Fleet Electrification and Operations, National Bureau of Economics, Energy Use in Transportation Conference, June 2020, Washington D.C.

[65] Alternative Fuel Vehicle Policy Interactions Increase U.S. Greenhouse Gas Emissions, Industry Studies Association, June 2020 (online).

[66] Effects of On-Demand Ridesourcing on U.S. Vehicle Ownership, Energy and Environmental Outcomes in the United States, January 2020, Washington D.C. (with J. Ward)

[67] Ride-Hailing Fleets Increase Vehicle Electrification and Reduce Emissions, January 2020, Washington D.C. (with M. Bruchon)

[68] Alternative Fuel Vehicle Policy Interactions Increase U.S. Greenhouse Gas Emissions, Transportation, Economics, Energy and Environment Conference, Oct 2019, Ann Arbor, MI.

[69] Effects of On-Demand Ridesourcing on U.S. Vehicle Ownership, Travel, Energy, and Environmental Outcomes, National Bureau of Economic Research, May 2019, Washington D.C.

[70] U.S. Federal and State Policy Interactions for Alternative Fuel Vehicles, Transportation Research Board Annual Meeting, Jan 10, 2018, Washington, D.C.

[71] On-Demand Ridesourcing Has Reduced Per-Capita Vehicle Registrations and Gasoline Use in U.S. States, Transportation Research Board Annual Meeting, Jan 2018, Washington D.C.

[72] Using Composite Vehicles in Choice Model Simulations: Implications on Prediction and Policy, Transportation Research Board Annual Meeting, Jan 2018, Washington D.C.

[73] U.S. Alternative Fuel Vehicle Policy Interactions Increase Greenhouse Gas Emissions, Transportation Research Board Annual Meeting, Jan 2017, Washington D.C.

[74] Consequential Life-Cycle Air Emissions Externalities for Plug-in Electric Vehicles in the PJM Interconnection, Transportation Research Board Annual Meeting, Jan 2016, Washington, D.C.

[75] Effect of Regional Grid Mix, Driving Patterns, and Climate on the Comparative Carbon Footprint of Electric and Gasoline Vehicles, Transportation Research Board Annual Meeting, Jan 2016, Washington, D.C.

[76] Unintended Consequences: Why U.S. Alternative Fuel Vehicle Adoption Increases Fleet Gasoline Consumption and Greenhouse Gas Emissions under Federal Corporate Average Fuel Economy and Greenhouse Gas Emission Policy, United States Association for Energy Economics, Oct 27, 2015, Pittsburgh, PA.

[77] Life Cycle Air Emissions Externality Implications of Electric Vehicle Adoption in the United States: A Comparison of Empirical and Normative Approaches, United States Association for Energy Economics, Oct 27, 2015, Pittsburgh, PA (speaker: Jaramillo).

[78] Emissions from Electric Vehicle Charging in the United States, Climate and Energy Decision Making Center Annual Meeting, May 21, 2015, Pittsburgh, PA.

[79] Forecasting Light-Duty Vehicle Demand using Alternative-Specific Constants for Endogeneity Correction vs. Calibration, Transportation Research Board Annual Meeting, Jan 14, 2015, Washington, DC.

[80] Emissions and Cost Implications of Controlled Electric Vehicle Charging in the PJM Interconnection, Transportation Research Board Annual Meeting, Jan 14, 2015, Washington, DC.

[81] Energy Implications of Partial Vehicle Automation, Transportation Research Board Annual Meeting, Jan 13, 2015, Washington, DC. (speaker: Hayeri).

[82] Greenhouse Gas Emissions from Alternative Fuel Vehicle Incentives in CAFE Policy, Transportation Research Board Annual Meeting, Jan 13, 2015 (poster), Washington, DC.

[83] A Techno-Economic Analysis and Optimization of Li-ion Batteries for Light-Duty Passenger Vehicle Electrification, Transportation Research Board Annual Meeting, Jan 13, 2015 (poster), Washington, DC.

[84] Regional Uncertainty and Variability of Electric Vehicle Life Cycle CO2 Emissions in the U.S., Transportation Research Board Annual Meeting, Jan 13, 2015 (poster), Washington, DC.

[85] Effects of Regional Temperature on Electric Vehicle Efficiency, Range and Emissions in the United States, Transportation Research Board Annual Meeting, Jan 12, 2015, Washington, DC (speaker: Yuksel).

[86] A Techno-Economic Analysis and Optimization of Li-ion Batteries for Light-Duty Passenger Vehicle Electrification, Carnegie Mellon Electrochemical Systems Group, Nov 14, 2014, Pittsburgh, PA.

[87] Regional Emissions from Electric Vehicles, Carnegie Mellon Electricity Industry Center, Oct 21, 2014, Pittsburgh, PA.

[88] Costs and Emissions Implications of Controlled Electric Vehicle Charging, Climate and Energy Decision Making Center Annual Meeting, May 20, 2014, Pittsburgh, PA.

[89] Consumer Preferences for Hybrid and Electric Vehicles in China and the United States: Implications for Policy and Environment, Transportation Research Board Annual Meeting, January 2014, Washington D.C. (speaker: Helveston).

[90] Sensitivity of Vehicle Market Share Predictions to Alternative Discrete Choice Model Specifications, Transportation Research Board Annual Meeting, January 2014, Washington D.C.

[91] Comparative Life-Cycle Cost of Electric Vehicle Battery Exchange Versus Fast Charging Stations, Transportation Research Board Annual Meeting, January 2014, Washington D.C.

[92] Influence of Driving Patterns on Life-Cycle Cost and Emissions of Hybrid and Plug-in Electric Vehicle Powertrains, Transportation Research Board Annual Meeting, January 2014, Washington D.C.

[93] Global Control Optimization of Electric Vehicles with Supercapacitor-Battery Systems Over a Set of Real-World Speed and Elevation Profiles via Dynamic Programming, Transportation Research Board Annual Meeting, January 2014, Washington D.C.

[94] Life Cycle Cost of Electric Vehicle Fast Charging and Battery Swapping Stations, INFORMS Annual Meeting, October 2013, Minneapolis, MN.

[95] Consumer Preferences for Hybrid and Electric Vehicles in China and the United States, INFORMS Annual Meeting, October 2013, Minneapolis, MN (speaker: Helveston).

[96] Sensitivity of Vehicle Market Share Predictions to Alternative Discrete Choice Model Specifications, ASME International Design Engineering Technical Conferences, August 2013, Portland, OR (speaker: Haaf).

[97] Toward Understanding the Role of Interaction Effects in Visual Conjoint Analysis, ASME International Design Engineering Technical Conferences, August 2013, Portland, OR (speaker: Sylcott).

[98] Electric Vehicles: A Techno-Economic and Environmental Assessment of Costs, Benefits, Challenges, and Strategies, Carnegie Mellon University (departmental seminar), April 26, 2013, Pittsburgh, PA.

[99] Cost-Effectiveness of PHEV Battery Capacity and Charging Infrastructure, Transportation Research Board of the National Academies, poster presentation, January 15, 2013, Washington, D.C.

[100] Evaluation of the Effects of Thermal Management on Battery Life in PHEVs, Transportation Research Board of the National Academies, poster presentation, January 15, 2013, Washington, D.C. (speaker: Yuksel)

[101] U.S. Residential Charging Potential for Plug-in Vehicles, Transportation Research Board of the National Academies, poster presentation, January 15, 2013, Washington, D.C. (speaker: Traut)

[102] Valuation of Plug-in Vehicle Life Cycle Air Emissions and Oil Displacement Benefits, Transportation Research Board of the National Academies, poster presentation, January 15, 2013, Washington, D.C.

[103] Influence of Driving Patterns on Life Cycle Benefits of Hybrid and Plug-in Electric Vehicles, International Mechanical Engineering Congress and Exposition, November 2012, Houston, TX. (speaker: Karabasoglu)

[104] Optimal Combined Design and Control of Electrified Vehicles for Globally Minimum Life Cycle Cost, International Mechanical Engineering Congress and Exposition, November 2012, Houston, TX. (speaker: Karabasoglu)

[105] Supercapacitor-Battery System Design and Control for Plug-in Electric Vehicles and Life Cycle Economic and Environmental Implications, International Mechanical Engineering Congress and Exposition, November 2012, Houston, TX. (speaker: Karabasoglu)

[106] Controlled Plug-in Vehicle Charging in High Wind Penetration Scenarios, INFORMS Annual Meeting, Oct 2012, Phoenix, AZ. (speaker: Weis)

[107] Globally Optimal Robust Design and Control of Plug-in Hybrid Electric Vehicles, INFORMS Annual Meeting, Oct 2012, Phoenix, AZ. (speaker: Karabasoglu)

[108] Global Control Optimization of Supercapacitor-Battery Electric Vehicles, INFORMS Annual Meeting, Oct 2012, Phoenix, AZ. (speaker: Karabasoglu)

[109] Driving Design: Modeling the Influence of Market Forces and Public Policy on Vehicle Design Decisions, National Science Foundation Civil, Mechanical, and Manufacturing Innovation Conference, July 23, 2012, Boston, MA.

[110] Development of a Simulation Model to Analyze the Effect of Thermal Management on Battery Life, SAE World Congress, April 25, 2012, Detroit, MI (speaker: Yuksel)

[111] Evaluation of the Effects of Thermal Management on Battery Life in Plug-in Hybrid Electric Vehicles, The Battery Congress, April 23, 2012, Ann Arbor, MI (speaker: Yuksel)

[112] Are Plug-in Vehicles Worth the Cost? Valuing Air Emissions and Oil Displacement Benefits in the U.S., INFORMS Annual Meeting, Nov 2011, Charlotte, N.C.

[113] Using Economic Input-Output Life Cycle Assessment to Guide Sustainable Design, INFORMS Annual Meeting, Nov 2011, Charlotte, N.C. (speaker: Traut)

[114] Optimal Design and Allocation of Electrified Vehicles and Dedicated Charging Infrastructure for Minimum Greenhouse Gas Emissions, INFORMS Annual Meeting, Nov 2011, Charlotte, N.C. (speaker: Traut)

[115] Minimizing the Integration Costs of Wind Using Curtailment and Electric Vehicle Charging, U.S. Association for Energy Economics North American Conference, Oct 2011, Washington D.C. (speaker: Weis)

[116] Robust Design for Profit Maximization under Uncertainty of Consumer Choice Model Parameters Using the Delta Method, ASME International Design Engineering Technical Conferences, Aug 2011, Washington D.C. (speaker: Heckmann)

[117 Using Economic Input-Output Life Cycle Assessment to Guide Sustainable Design, ASME International Design Engineering Technical Conferences, Aug 31, 2011, Washington D.C.

[118] Are Plug-in Vehicles Worth the Cost?, ASME International Design Engineering Technical Conferences, Aug 30, 2011, Washington D.C.

[119] A Perspective on Rebound Effects and Demand/Supply Equilibrium, 2011 Climate and Energy Decision Making Workshop, June 2011, Washington D.C. (speaker: Hendrickson)

[120] NHTS Survey Day Driving Distance and Estimated Variability to inform Electric Vehicle Range Design, Using National Household Travel Survey (HNTS) Data for Transportation Decision Making Workshop, June 2011, Washington, D.C. (speaker: Traut)

[121] Costs and Benefits of Plug-in Vehicles, Carnegie Mellon Steinbrenner Media Fellowship, June 2011, Pittsburgh, PA.

[122] Optimal Design and Allocation of Electrified Vehicles and Dedicated Charging Infrastructure for Minimum Greenhouse Gas Emissions, International Society of Industrial Ecology Conference, June 2011, Berkeley, CA. (speaker: Traut)

[123] Techno-Economic Analysis of Lithium-Ion Batteries for Personal Vehicle Electrification, with Apurba Sakti, Technology Management and Policy Conference, May 2011, State College, PA.

[124] Optimal Design and Allocation of Electrified Vehicles and Dedicated Charging Infrastructure for Minimum Greenhouse Gas Emissions, Mascaro Center's Engineering Sustainability Conference 2011, April 2011, Pittsburgh, PA.

[125] Air Emissions and Oil Displacement Benefits from Plug-in Vehicles, policy brief presented to members of the Congressional Budget Office, the Congressional Research Service, the Senate Energy and Natural Resources Committee, the Senate Commerce, Science and Transportation Committee, and members of the U.S. House of Representatives, March 13-14, 2012, Washington, D.C.

[126] Techno-Economic Analysis of Lithium-Ion Batteries for Personal Electrification, with Apurba Sakti. National Academies Transportation Research Board Annual Meeting, January 23-27, 2011, Washington, D.C.

[127] Optimal Design and Allocation of Electrified Vehicles and Dedicated Charging Infrastructure for Minimum Greenhouse Gas Emissions, with Elizabeth Traut, National Academies Transportation Research Board Annual Meeting, January 23-27, 2011, Washington D.C.

[128] Driving Design: Modeling the Influence of Market Forces and Public Policy on Vehicle Design Decisions, Civil, Mechanical and Manufacturing Innovation Conference, January 4-7, 2011, Atlanta, GA.

[129] Material Use, Infrastructure Change, and Environmental Impacts of Alternative Fuels and Vehicles, Civil, Mechanical and Manufacturing Innovation Conference, January 4-7, 2011, Atlanta, GA.

[130] Are Plug-in Vehicles Worth the Cost?, INFORMS Annual Meeting, Nov 9, 2010, Austin, TX.

[131] A MINLP Model for Global Optimization of Plug-in Vehicle Design and Allocation to Minimize Life Cycle Cost and Greenhouse Gas Emissions, INFORMS Annual Meeting, Nov 8, 2010, Austin, TX.

[132] Why Your Plug-in Hybrid Electric Vehicle with a 40-mile Battery May Only Go 25, with Orkun Karabasoglu, INFORMS Annual Meeting, Nov 9, 2010, Austin, TX.

[133] Optimal Plug-in Hybrid Electric Vehicle Design and Allocation for Minimum Life Cycle Cost, Petroleum Consumption, and Greenhouse Gas Emissions, ASME International Design Engineering Technical Conferences, Advanced Vehicle and Tire Technology Conference, Aug 2010, Montreal, CA.

[134] A MINLP Model for Global Optimization of Plug-in Hybrid Electric Vehicle Design and Allocation to Minimize Life Cycle Greenhouse Gas Emissions, ASME International Design Engineering Technical Conferences, Design Automation Conference, Aug 2010, Montreal, CA.

[135] MINLP Global Optimization of Plug-in Hybrid Vehicle Design and Allocation for Minimum Cost and GHG Emissions, INFORMS Conference on Energy, Sustainability and Climate Change, Feb 2010, Gainesville, FL, USA.

[136] Do More Batteries Make a Plug-in Better? Economic and Environmental Analysis of Plug-in Hybrid Electric Vehicles, Society of Automotive Engineers Government-Industry Meeting, Jan 2010, Washington D.C., USA.

[137] Do More Batteries Make a Plug-in Better? Economic and Environmental Analysis of Plug-in Hybrid Electric Vehicles, Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting, Oct 11, 2009, San Diego, CA, USA.

[138] Optimal Plug-in Hybrid Electric Vehicle Design and Allocation for Diverse Driving Patterns, ASME Design Engineering Technical Conferences, Sept 1 2009, San Diego, CA, USA.

[139] Do More Batteries Make a Plug-in Better? Economic and Environmental Analysis of Plug-in Hybrid Electric Vehicles, MIT Engineering Systems Symposium, June 17, 2009, Boston, MA, USA.

[140] A Structural Analysis of Vehicle Design Responses to Corporate Average Fuel Economy (CAFE) Policy, poster presentation, MIT Engineering Systems Symposium, June 16, 2009, Boston, MA, USA.

[141] Economic, Environmental, and Security Implications of Plug-in Hybrid Electric Vehicles, Presented to staff members of the House Energy and Commerce Committee, the House Committee on Science and Technology, the Select Committee on Energy Independence and Global Warming, the Congressional Research Service, and offices of U.S. House and Senate members, April 16 and April 20, 2009, Washington D.C., USA.

[142] A Structural Analysis of Vehicle Design Responses to CAFE Policy, National Academies Transportation Research Board Annual Meeting, January 2009, Washington DC, USA.

[143] Impact of Battery Weight and Charging Patterns on the Economic and Environmental Benefits of Plug-in Hybrid Vehicles, National Academies Transportation Research Board Annual Meeting, January 2009, Washington DC, USA.

[144] A Structural Analysis of Vehicle Design Responses to CAFE Policy, Institute for Operations Research and Management Sciences (INFORMS) Annual Meeting, November 2008, Washington, DC, USA.

[145] A Deterministic Lagrangian-Based Global Optimization Approach for Decomposable Nonconvex Mixed-Integer Problems, Institute for Operations Research and Management Sciences (INFORMS) Annual Meeting, November 2008, Washington, DC, USA.

[146] Optimal Product Design in a Competitive Market, Institute for Operations Research and Management Sciences (INFORMS) Annual Meeting, November 2008, Washington, DC, USA.

[147] Consumer Heterogeneity and Channel Structures in Optimal Product Design, Institute for Operations Research and Management Sciences (INFORMS) Annual Meeting, November 2008, Washington, DC, USA.

[148] Global Optimization of the Joint Product Family Platform Selection and Design Problem, Institute for Operations Research and Management Sciences (INFORMS) Annual Meeting, November 2008, Washington, DC, USA.

[149] Impact of Battery Weight and Charging Patterns on Plug-in Hybrid Vehicles, ASME International Design Engineering Technical Conferences, August 2008, New York, NY, USA.

[150] Should Designers Worry about Market Systems?, ASME International Design Engineering Technical Conferences, August 2008, New York, NY, USA.

[151] Optimal Product Design under Price Competition, ASME International Design Engineering Technical Conferences, August 2008, New York, NY, USA.

[152] A Deterministic Lagrangian-based Global Optimization Approach for Large-Scale Decomposable Problems, ASME International Design Engineering Technical Conferences, August 2008, New York, NY, USA.

[153] Wiki-Based Learning in the Mechanical Engineering Classroom, American Society for Engineering Education (ASEE) Annual Conference and Exposition, June 2008, Pittsburgh, PA, USA.

[154] Applications of Lagrangian Branch and Cut for Hierarchical Engineering Systems, Institute For Operations Research and the Management Sciences (INFORMS) Annual Meeting, November 2007, Seattle, WA, USA.

[155] A Quantitative Approach to Achieving Optimal Balance between Product Variety and Manufacturability, Institute For Operations Research and the Management Sciences (INFORMS) Annual Meeting, November 2007, Seattle, WA, USA.

[156] Product Line Design Optimization for Heterogeneous Markets, Institute For Operations Research and the Management Sciences (INFORMS) Annual Meeting, November 2007, Seattle, WA, USA.

[157] Diagonal Quadratic Approximation for Parallelization of Analytical Target Cascading, ASME International Design Engineering Technical Conferences, September 2007, Las Vegas, NV, USA.

[158] A Game Theoretic Approach to Finding Market Equilibria for Automotive Design under Environmental Regulation, ASME International Design Engineering Technical Conferences, September 2007, Las Vegas, NV, USA.

[159] Design Optimization of a Laptop Computer using Aggregate and Mixed Logit Demand Models with Consumer Survey Data, ASME International Design Engineering Technical Conferences, September 2007, Las Vegas, NV, USA.

[160] Measurement of Headlight Form Preference using Choice-Based Conjoint Analysis, ASME International Design Engineering Technical Conferences, September 2007, Las Vegas, NV, USA.

[161] An Extension of the Commonality Index for Product Family Optimization, ASME International Design Engineering Technical Conferences, September 2007, Las Vegas, NV, USA.

[162] A Single-Stage Gradient-Based Approach for Solving the Joint Product Family Platform Selection and Design Problem using Decomposition, ASME International Design Engineering Technical Conferences, September 2007, Las Vegas, NV, USA.

[163] A Decomposed Genetic Algorithm for Solving the Joint Product Family Optimization Problem, AIAA Multidisciplinary Design Optimization Specialists Conference, April, Honolulu, Hawaii, USA.

[164] Balancing Marketability and Manufacturability in Product Line Design Optimization, Institute For Operations Research and the Management Sciences (INFORMS) Annual Conference, November 2006, Pittsburgh, PA.

[165] The Impact of Environmental Policy on Profit-Driven Vehicle Design Optimization, Institute For Operations Research and the Management Sciences (INFORMS) Annual Conference, November 2006, Pittsburgh, PA.

[166] Analytical Target Cascading using Branch and Bound for Mixed Integer Nonlinear Programming, ASME International Design Engineering Technical Conferences, September 2006, Philadelphia, PA, USA.

[167] Balancing Marketing and Manufacturing Objectives in Product Line Design, ASME International Design Engineering Technical Conferences, September 2005, Long Beach, CA, USA.

[168] An Efficient Weighting Update Method to Achieve Acceptable Consistency Deviation in Analytical Target Cascading, ASME International Design Engineering Technical Conferences, September 2004, Salt Lake City, Utah, USA.

[169] An Efficient Weighting Update Method to Achieve Acceptable Consistency Deviation in Analytical Target Cascading, Automotive Research Center Conference, May 2004, Ann Arbor, MI, USA.

[170] An Optimal Marketing and Engineering Design Model for Product Development Using Analytical Target Cascading, Tools and Methods of Competitive Engineering Conference, April 2004, Lausanne, Switzerland.

[171] A Simulation-based Vehicle Design Strategy for Requirements Validation, Automotive Research Center Conference, May 12, 2003, Chrysler Headquarters, Auburn Hills, MI, USA.

[172] A Study of Emission Policy Effects on Optimal Vehicle Design Decisions, ASME Design Engineering Technical Conferences, September 2003, Chicago, IL, USA.

VIDEOS

[1] Did You Know That Extreme Weather Affects an Electric Car's Range? Inside Science, Nov 2015

[2] Electric Vehicle Benefits & Costs in the U.S., Carnegie Mellon University, June 2015

[3] Electric Vehicle Adoption Potential in the U.S., Carnegie Mellon University, June 2015

[4] Is Manufacturing in China a Wise Decision for a Small, Innovative US Company? Carnegie Mellon University Scott Institute for Energy Innovation, June 2015

[5] Jeremy Michalek: Vehicle Electrification, Carnegie Mellon University, April 2015

[6] CMU Energy Interview: Jeremy Michalek, Carnegie Mellon University, July 2013.

[7] Do Hybrid and Plug-in Cars Really Save the Environment? Carnegie Mellon University Scott Institute for Energy Innovation, Nov 2013

[8] CMU Energy Presentation: Plug-in Vehicles, Carnegie Mellon University, Sep 2012

RADIO AND PODCASTS

[9] On Point, National Public Radio, WBUR: America's Electric Vehicle Future, June 2021

[10] Energy Bite, WESA-Pittsburgh: Are electric vehicles the right choice for you? July 2015

[11] Energy Bite, WESA-Pittsburgh: If I buy a plug-in electric vehicle, how much will it help the environment? July 2015

[12] Energy Bite, WESA-Pittsburgh: Will everyone be driving a plug-in electric vehicle in the future? July 2015

[13] Energy Bite, WESA-Pittsburgh: If I buy a plug-in electric vehicle, when is the most efficient time to charge it? July 2015

[14] Energy Bite, WESA-Pittsburgh: Will automated vehicles help save energy? July 2015

[15] Carnegie Mellon Engineering: What do American and Chinese consumers want in an electric vehicle? May 2015

[16] Carnegie Mellon Engineering: How does climate affect your electric car's performance? April 2015

PRESS RELEASES

[1] Should Uber and Lyft be electrifying more vehicles? Feb 19, 2021.

[2] When Uber and Lyft enter cities, vehicle ownership increases, Jan 6, 2021.

[3] Want an Electric Vehicle? The One You Should Buy Depends on Where You Live, Apr 20, 2016.

[4] Federal Policy Reverses Benefits of Alternative Fuel Vehicles, Mar 3, 2016.

[5] Researchers Show Coal Retirement Needed for Electric Vehicles to Reduce Air Pollution, Feb 23, 2016.

[6] Charging Electric Vehicles at Night Can Cause More Harm Than Good, Says CMU Study, Feb 22, 2016.

[7] Which Vehicle Holds Smallest Carbon Footprint? Electrics in Some Regions, Hybrids in Others, Says Carnegie Mellon Study, July 16, 2015

[8] Carnegie Mellon Study Shows Electric Vehicle Range and Emissions Vary With Climate, Feb 24, 2015

[9] CMU Study Finds Chinese Consumers May Adopt Electric Vehicles First, Impacting Auto Market, Feb 16, 2015.

[10] Big Factories Won't Solve High Cost of Electric Vehicles, Carnegie Mellon Researchers Say, Oct 21, 2014

[11] Carnegie Mellon Study Says Electric Vehicles Could Be Cheaper to Recharge if Electricity Providers Control Charging Speeds, Jan 23, 2014

[12] Carnegie Mellon Researchers Find Consumers Choose More Efficient Light Bulbs when Energy Costs are Labeled, Jan 10, 2014.

[13] Carnegie Mellon Researchers Find Limited Residential Parking a Barrier to Electric Vehicle Adoption, Nov 11, 2013.

[14] Carnegie Mellon Researchers Report Hybrid Cars are Greener for City Drivers, June 17, 2013.

[15] Fiscal Cliff Bill Tax Credits for Electric Vehicle Chargers Found Not Cost Effective, Jan 7, 2013.

[16] Carnegie Mellon Study Finds Benefits of Plug-in Vehicles Depend on Battery Size, Sept 26, 2011.

OP-EDS

[1] MarketWatch: I'm an EV expert, and I'm skeptical about how quickly electric cars will go mainstream in the U.S., June 2021.

[2] Michalek, J., "Problems with the fuel economy rollback," Op-Ed, The Hill, Sept 26, 2018.

SELECTED MEDIA STORIES

[3] On Point, National Public Radio, WBUR: America's Electric Vehicle Future, June 2021

[4] The New York Times: How green are electric vehicles? Mar 2, 2021.

[5] The Hill: Buttigieg sets goals for electric, automated freight vehicles, Feb 17, 2021.

[6] Scientific American: Can California Eliminate Gas Cars? Nov 8, 2017.

[7] The New York Times: Climate Protection Advocates Fear a Rollback of Emissions Standards, Nov 14, 2016.

[8] Science: The Best - and Worst - Places to Drive Your Electric Car, Feb 20, 2015.

[9] National Public Radio On-Point: A Dire Climate Change Report, and the Possibility for Change, Nov 6, 2014.

[10] The New York Times: EVs Could Be a Key Part of a Changing Electricity Grid, Jan 23, 2014.

[11] The Daily Beast: Electric Vehicles May Be the Green Car of the Future, But Hybrids Are the Green Car of the Present, Jan 24, 2013.

[12] The Washington Post: Hybrid, electric or gas: What's a car buyer interested in the environment to do? March 19, 2012.

[13] Science: Editors' Choice: The Pros (and Cons) of Plugging In, V331, Feb 18 2011.

ALL MEDIA STORIES

[1] WHYY: SEPTA's cracking battery buses raise questions about the future of electric transit, July 15, 2021.

[2] Vice (Motherboard): Uber and Lyfts can be electrified now, but drivers aren't so sure, June 28, 2021.

[3] On Point, National Public Radio, WBUR: America's Electric Vehicle Future, June 17, 2021

[4] IEEE Spectrum: How is this a good idea? EV battery swapping, May 13, 2021.

[5] The Seattle Times: Are electric vehicles really as green as advertised? March 6, 2021.

[6] The New York Times: How green are electric vehicles? Mar 2, 2021.

[7] Green Car Congress: CMU study finds taxes on emissions would result in more rapid electrification by ridesharing companies, Feb 21, 2021.

[8] The Hill: Buttigieg sets goals for electric, automated freight vehicles, Feb 17, 2021.

[9] Shift: Oh, great – Uber and Lyft are actually increasing car ownership in US cities, Jan 13, 2021.

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Richard A. Rykowski

EDUCATION

Bachelor Degree in Chemical Engineering, University of Michigan, 1975
Master's Degree in Chemical Engineering, University of Michigan, 1977
Business, 30 credits towards MBA, University of Michigan, 1987-1992

EMPLOYMENT

Independent engineering contractor to Environmental Defense Fund, 2016 to present

U.S. Environmental Protection Agency, Ann Arbor, Michigan 1977-1993, 1996-2010

15 years as a Senior Technical Advisor in the Office of Transportation Air Quality, focusing on technological and economic analysis used in regulatory development

Lead architect for development of OMEGA, used in support of the EPA GHG standards for passenger cars and light trucks for model years 2012-2016 and 2017-2025

Co-team leader for development of Tier 2 standards for light-duty vehicles, 10 ppm gasoline sulfur standard, 10 ppm on-road and non-road diesel fuel sulfur standards

Project manager for reformulated gasoline standards, gasoline RVP standards and the initial fine PM standards for cars and light trucks and heavy-duty vehicles, as well as later standards for fine PM emissions from heavy-duty vehicles and nonroad equipment

Air Improvement Resource, 1993-1996

Chemical engineering consultant, clients included: ARCO Chemical, Motor Vehicle Manufacturers Association, General Motors, Engine Manufacturers Association

PUBLICATIONS

Rykowski, Richard, "The Benefits of Protective Advanced Clean Car Standards in Colorado An Examination of Cost Savings, Greenhouse Gas Emission Reductions, and Health Benefits", for EDF, May 2018, The_Benefits_of_Protective_Clean_Car_Standards_CO.pdf (edf.org)

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Numerous EPA reports, U.S. Environmental Protection Agency | US EPA, search on "Rykowski"

Authored numerous sections of the preambles and regulatory impact analyses associated with the above-mentioned EPA rulemakings

AWARDS

1984 EPA Engineer of the Year, Numerous Gold and Silver Medals for Meritorious Service, received both as an individual and as a member of a project team

APPENDIX B

CHARGE TO REVIEWERS

Technical Charge to External Peer Reviewers

Contract No. 68HE0C18C0001
Work Assignment 3-05
November 2021

External Peer Review of EPA's OMEGA Model

BACKGROUND

EPA created OMEGA version 1.0 to analyze new GHG standards for light-duty vehicles proposed in 2011. In the period since the release of the initial version, there have been significant changes in the light duty vehicle market including technological advancements and the introduction of new mobility services. Advancements in battery electric vehicles (BEVs) with greater range, faster charging capability, and expanded model availability, as well as potential synergies between BEVs, ride-hailing services and autonomous driving are particularly relevant when considering pathways for greater levels of emissions reduction in the future. OMEGA version 2.0 has been developed with these trends in mind. The model's interaction between consumer and producer decisions allows a user to represent consumer responses to these new vehicles and services. The model now also has been designed to have expanded capability to model a wider range of GHG program options, which is especially important for the assessment of policies that are designed to address future GHG reduction goals.

Like the prior releases, this latest version is intended primarily to be used as a tool to support regulatory development by providing estimates of the effects of policy alternatives under consideration. These effects include the costs associated with emissions-reducing technologies and the monetized effects normally included in a societal benefit-cost analysis, as well as physical effects that include emissions quantities, fuel consumption, and vehicle stock and usage.

ELEMENTS TO BE ADDRESSED

EPA's OMEGA estimates the technology necessary for vehicle manufacturers to meet a specified greenhouse gas (GHG) standard. The model is contained in the enclosed computer program and the documentation located at: *https://omega2.readthedocs.io/en/2.0.0/* . This report illustrates the concepts and methodologies behind EPA's OMEGA model. **No independent data analysis will be required for this review.**

Specifically, EPA is seeking your expert opinion on the concepts and methodologies upon which the model relies and whether or not the model will execute these algorithms correctly.

In making your comments, please distinguish between recommendations for clearly defined improvements that can be readily made based on data or literature reasonably available to EPA and improvements that are more exploratory or dependent on information not readily available to EPA. Any comment should be sufficiently clear and detailed to allow a thorough understanding by EPA or other parties familiar with the model.

Please review and comment on the following items:

1. The overall approach to the specified modeling purposes, the specific approaches chosen for modeling individual modules, and the particular methodologies chosen to achieve that purpose.
2. The appropriateness and completeness of the contents of the sample input files. EPA is not seeking comment on the particular values of the contents of the input files, which are samples only.
   NOTE: The types of information which can be input to the model point to both the flexibilities and constraints of the model.
3. The accuracy and appropriateness of the model's conceptual algorithms and equations for technology application, market impacts, and calculation of compliance.
4. Clarity, completeness, and accuracy of the documentation.
5. The congruence between the conceptual methodologies and the program execution. **NOTE:** This can be verified by comparing spreadsheet calculations to the outputs provided by EPA or by changing the input values and examining the results with good engineering judgment.
6. Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed.
7. Recommendations for any functionalities beyond what EPA has described as "future work."