Peer Review of the Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA) and EPA's Response to Comments

EPA United States Environmental Protection Agency

Peer Review of the Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA) and EPA's Response to Comments

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

Prepared for EPA by
Southwest Research Institute
EPA Contract No. EP-C-05-018
Work Assignment No. 4-01

NOTICE

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

EPA United States Environmental Protection Agency

EPA-420-R-09-016
September 2009

In May, 2009, EPA contracted with the Southwest Research Institute (SwRI) to conduct a peer review of a new model which evaluates the technology and cost associated with reducing greenhouse gas (GHG) emissions from light-duty motor vehicles. This model is currently referred to as the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). When peer review was initiated, the model was referred to as the Vehicle Greenhouse Gas Emissions Cost and Compliance Model (VECTOR).

The three peer reviewers selected by SwRI were John German, Dr. Paul Leiby and Dr. Rubin. EPA would like to extend its appreciation to all three reviewers for their efforts in evaluating this model. The three reviewers brought useful and distinctive views to all aspects of the model's use. This included setting up the input files appropriately, running the model efficiently, and understanding the model's outputs. There are two major sections to this report. The first section contains the final SwRI report summarizing the peer review of OMEGA, including the detailed comments of each peer reviewer and an overview of the most significant comments compiled by SwRI. The SwRI report also contains the peer review charge letter. The second major section contains our responses to the peer reviewers' comments. In this section, we repeat the detailed comments from each commenter and, after each section of comments, provide our response. We have retained the organization reflected in each reviewer's comments to aid the reader in moving from the SwRI report to our responses.

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Peer Review of the EPA Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA)

Office of Transportation Air Quality
U.S. Environmental Protection Agency

September, 2009

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June 9, 2009

To: Environmental Protection Agency
Contracts Management Division
26 West Martin Luther King Drive
Cincinnati, OH 45268

Attention: Ms. Almethyist A. Chambers
Contracting Officer

From: Patrick M. Merritt
Senior Research Scientist
Emissions Research and Development Department
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

Subject: Final Report for Work Assignment 4-1, "Facilitation of an Independent Peer Review Process for EPA's VGHG Model"

Contract No. EP-C-05-018, under SwRI Project 03.14658.01
Contract Title: "Testing and Analytical Support for Regulation of Motor Vehicles, Engines, Fuels, and Fuel Additives"

I. INTRODUCTION

On-road vehicles are the predominant source of greenhouse gas (GHG) emissions in the transportation sector (principally, CO_2 and hydrocarbon emissions from vehicle air conditioners). Of all on-road vehicles, light-duty passenger cars and trucks produce the majority of these GHG emissions. As EPA's Office of Transportation and Air Quality explores the regulation of CO_2 and other GHG emission control measures in on-road and non-road vehicles and equipment, there is a need to evaluate the costs and benefits of any such regulations. As such, EPA has developed its Vehicle Greenhouse Gas Emissions Cost and Compliance Model, or VGHG model, to facilitate its analysis of the costs and benefits of the control of GHG emissions from cars and trucks. Broadly speaking, the primary cost of GHG emission control is the cost of adding technology to the vehicles, while the primary benefit is the value of reduced fuel consumption in those same vehicles.

The EPA VGHG model is used to apply various technologies to a defined set of vehicles in order to meet a specified GHG emission target, and to then calculate 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. Fleet wide average GHG emissions can also be used to estimate a wide array of societal costs and benefits associated with the reduction of GHG emissions.

To assure the highest quality science in its predictive assessments, EPA has engaged SwRI to facilitate an independent peer review of its model for determining the costs and benefits of changes to vehicle technology for the reduction of GHG emissions from passenger cars and trucks. EPA needs assurance that the proposed structure (and development process) of its VGHG model will result in a model that is viable, accurate, and well-suited for the diversity of uses to which it may be applied. This report documents the process followed towards that end.

II. TECHNICAL DISCUSSION

EPA's peer review guidelines specify that all highly significant scientific and technical work products undergo independent peer review per specific agency protocols. The first task was to select panel members (three) who were qualified, interested, and had time available to devote to an in-depth review.

Selection of candidates was made from a list of persons familiar with the issues involved in GHG emissions from ecological, socio-economic, regulatory, and manufacturing perspectives. The panel members who were selected have impressive standings in their respective fields and comprise a balanced and diverse point of view. The peer review panel consists of the following individuals:

- John German, *The International Council on Clean Transportation*
- Paul Leiby, *Oakridge National Laboratory*
- Jonathan Rubin, *University of Maine, School of Economics*

Their résumés are presented in Appendix A. Following selection and determination of their availability, consultancy agreements had to be put in place with each individual.

As soon as it was practical, the documents and software were distributed to the review panel members. The distribution was accomplished by preparing a charge letter describing what was requested in detail, and attaching the supporting documents. Please see Appendix B.

SwRI then arranged a teleconference between the peer reviewers and EPA technical staff as a kick-off meeting. In that conference, held on May 1, 2009, the charge to the reviewers was discussed, and the presentation of the supporting documents was reviewed. As there were seven attachments, it was important to have assurance that everyone understood how the documents, appendices, and attachments are related.

During the kick-off meeting, an informal question dialog allowed panel members to interact with EPA's work assignment manager (WAM) and the technical staff who are most familiar with the GHG model. It was agreed that any further questions would be submitted in writing to SwRI, and the question and EPA's response would be distributed to all reviewers. Only one such question was submitted. Finally, it was agreed that each would attempt to complete their work prior to the next teleconference, which was scheduled for May 28, 2009.

The review documents of two of the three reviewers had been received and forwarded to EPA before the teleconference held on May 28th. The third followed shortly thereafter. The May 28th teleconference was nonetheless productive, with discussion among EPA technical staff and the panel members. Those documents are presented in Appendices C, D, and E.

Because the third document had not been received before the teleconference, it was determined that another teleconference would be held. The idea was that all parties could have additional time to read the comments of each of the panel members and determine if there are other topics or issues that need clarification or discussion. That discussion was also productive, with discussion of whether one equation had an error or if it simply needed more explanation, for example. In addition, investment costs of technology with regards to tooling and plant conversions, capital budgets, and lead time were also discussed.

III. SUMMARY

A very brief summary of each of the three reviewers' comments is presented below.

Paul Leiby:

- Stay focused first on clearly and rigorously modeling the fuel-economy technology choice and cost-effectiveness considerations, for various GHG emission levels.
- It is essential to be very explicit about *whose* behavior and objectives are being modeled.
- Some confusing terms are included in the TARF, most notably the non-standard way in which VMT is discounted for the purposes of this TARF (See equation top of page 11, line 1).
- The inclusion of "IR" ("the annual increase in the value of CO2") in the discount factor is done without explanation or justification. (Is it meant to be the growth rate in GHG damages, abatement cost, or a CO2 tax?).
- CostEff TARF would not seem to be a consideration for vehicle manufacturers whose objective is to produce a new-car fleet meeting consumer needs and a GHG emission standard at least cost. What objective was intended with this hybrid aspect of the TARF?
- Model Documentation:
    - Restructure the presentation, perhaps following the pattern of a journal article (e.g., begin with stated purpose and background. Place this model in the constellation of related models and indicate what is different and why. Describe approach, data sources, sample results.)
    - Bringing description of the "Core Program" and what the model does toward the front.
    - Clarify and condense the model description
    - State model objective (typically stating what is maximized, minimized, or what final solution condition is sought)
    - State model constraints
    - State and discriminate between principle decision variables, exogenous inputs, parameters, and internally calculated results
    - State the solution algorithm and termination condition
    - Be rigorous in use of notation.
    - Use consistent variable names
    - Clarify subscripts and carefully apply them
    - Carefully state units.
- Appropriateness and completeness of the contents of the sample input files:
    - In all data input files, specify units
    - The "Data Validation" capability and error report is a very useful feature
- Fuels input file, Appendix 4
    - This list does not yet reflect biofuels or renewable fuels
    - Some provision may be needed for the variable energy and GHG content of gasoline
    - Provision may also be needed for E 85, and the uncertain fraction of E85 used by FFVs.

- The net fuel economy and emissions by PHEVs
- Calculation of compliance to attribute-based standards:
    - On page 7, equation for the logistic-based footprint, there appears to be a sign error in the denominator (should be $1+\exp((x-C)/D)$ not $1-\exp((x-C)/D)$). This is likely a typo in the documentation alone.
    - No discussion or provision for market-based (permit trading) standards is yet made. This should at least be acknowledged.
    - One strategy for doing more flexible standards would be to simply merge the datasets and technology-sequence stage for all manufacturers and vehicle types in a trading group. However, this would not provide information about potential permit prices and burdens across manufacturers.
- Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed:
    - It would be very helpful to have some graphical summaries of the input and output results.
    - All output files should embed clear documentation on the inputs used.
    - The .log file does list names of the 4 input files, which is essential.
    - The "Visualization Output" file does not (yet) report the input files (but the information could be retrieve from the XML file).

<u>John German:</u>

- "Accounting model" has advantage of simplicity, avoids "overmodeling." However, it "requires a great deal more sophistication and work by anyone using the model to prepare the inputs properly."
- Modeling by redesign cycles (rather than annually) is a good idea.
- Leadtime issues modeled far too simplistically
    - One of the most important issues in standard setting
    - Inappropriate to treat all manufacturers the same, regards potential penetration rates and costs for adding technologies (given differing experience)
    - No such thing as a hard cap on technology penetration rates
- Recommends handling leadtime constraints and tech penetration with an assessment of capital costs by each manufacturer, with a capital budget each design cycle
    - [Q: How would that budget be set?]
- Short-term: use manufacturer-specific caps on max penetration rate *per year*
- Use max penetration caps (total) to reflect market restrictions (demand limits) rather than leadtime constraints
- Re: rank-ordering technologies for each vehicle type: "Requiring the user to input technology in rank order of cost-effectiveness" has some challenges.
    - Requires a great deal of analysis to create model inputs: "real analyses and modeling are in these input files"

    - "It only works if the learning rate is the same for all technologies and if no technology changes effectiveness over time."
    - "model must be able to handle multiple pathways" of technical progression
    - Synergies depend on order of introduction (?) and must be assessed according to different pathways
- Very valuable, perhaps ultimately necessary for regulatory evaluation, to allow model to "maximize net social value"

<u>Jonathan Rubin:</u>

- Be clear and explicit about "accounting stance"
    - "costs to whom?"
- Describe and report costs and benefits to as many as three groups (consumers, manufacturers, society)
    - Account for subsidies and taxes
    - Show component costs
    - Allow distinct discount rates and treatment of risk for the three groups
- Improve notation, consistent use of subscripts
- Concerns about certain formulations in model equations
    - 1/i in FS equation
    - Discounting factors used
- Avoid discounting physical quantities, and mixing physical phenomena with economic costs and benefits
- Need to account for environmental and fuel economy implications of alternative fuels more carefully
    - Renewable and biofuels
    - Electricity
- Future work:
    - Significant enhancement: make probabilistic, reflecting uncertainty
    - Account for hedonic (vehicle attribute) implications of large changes in GHG emissions
    - Consider implications for gas excise tax revenue
    - User manual, describing impact and power of key assumptions
    - Output in SI units

IV. CLOSING

Southwest Research Institute has prepared this final report to Work Assignment 4-1 to describe the process followed in the peer review of the EPA's Vehicle Greenhouse Gas Model. Please contact Patrick Merritt at 210-522-5422 (e-mail pmerritt@swri.org) with any questions. Thank you for this opportunity to be of service.

Prepared by:

Patrick M. Merritt
Senior Research Scientist
Emissions Chemistry
Emissions Research and Development

Reviewed by:

E. Robert Fanick
Manager
Emissions Chemistry
Emissions Research and Development

Approved:

Jeff J. White, Director
Emissions Research and Development
Engine, Emissions and Vehicle
Research Division

/tyd

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c: Christine Brunner, EPA NVFEL
Kent Helmer, EPA NVFEL
Richard Rykowski, EPA NVFEL
Sherry Twilligear, SwRI Contracts

ATTACHMENT

APPENDIX A

RÉSUMÉS OF PEER REVIEW PANEL MEMBERS

- John German, *The International Council on Clean Transportation*
- Paul Leiby, *Oakridge National Laboratory*
- Jonathan Rubin, *University of Maine, School of Economics*

John M. German

730 Brooks St., Ann Arbor, MI 48103

(734) 213-0537 (H) (734) 222-5962 (W)

PROFESSIONAL EMPLOYMENT

January 2009 to present	**SENIOR FELLOW, INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION** • Primary responsibility for technology innovation and U.S. policy development. • Managing project to track technology costs and benefits worldwide.
February 1998 to January 2009	**MANAGER, ENVIRONMENTAL AND ENERGY ANALYSIS, PRODUCT REGULATORY OFFICE, AMERICAN HONDA MOTOR CORPORATION** • Provide policy and technical analyses on vehicle-related 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, 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 revisions to the Federal Test Procedure. Created and managed extensive usage of teams across organizational boundaries. • Managed the development of a nonroad emission inventory and the issuance of the Nonroad Engine and Vehicle Emission Study. • Managed rulemaking for Cold Temperature Carbon Monoxide Standards. • Worked with transporatation planners to help create and develop a computer simulation model for vehicle emissions. • 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. • Developed initial concepts for On-Board Diagnostics. • Created and managed rulemaking assessing LDT CAFE test procedure adjustments. • Developed policy guidance for 48" roll electric dynamometer, driver-selectable devices, mileage accumulation fuel requirements, coastdown procedures and 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. • Planned and coordinated activities of staff. • 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 impacts of future product changes on CAFE. • Team leader on a project with all areas of engineering to implement Shift Indicator Lights. Independently developed computer algorithms to eliminate cost of a sensor.
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 the corporate expert on fuel economy regulations, coordinated fuel economy testing, served as liaison with EPA, helped write responses to proposed regulations, and worked on special projects.

AWARDS and ADVISORY COMMITTEES

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" AT SAE GOVERNMENT/INDUSTRY MTG.**
2004	Barry McNutt Award for Excellence in Automotive Policy Analysis **1ST RECEIPIENT 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

PUBLICATIONS

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 Gaseoline-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.

K. Aoki, K. Nakano, J. German, S. Kajiwara, H. Sato, and Y. Yamamoto, "An Integrated Motor Assist Hybrid System – Development of the Insight, a Personal Hybrid Coupe", SAE 2000-01-2216, 2000.

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.

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.

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

Insert file

Leiby Paul N. resume_2.0page_2008May02.pdf

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Rubin%20CV.pdf

APPENDIX B

CHARGE LETTER TO REVIEWERS

SOUTHWEST RESEARCH INSTITUTE®

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (210) 684-5111 • www.swri.org
ENGINE, EMISSIONS, AND VEHICLE RESEARCH DIVISION HTTP://ENGINEANDVEHICLE.SWRI.ORG
FAX: (210) 522-3950

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Gentlemen:

Thank you for agreeing to review EPA's proposed vehicle emission effects model which 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, *Description and Methodologies of the EPA Vehicle Greenhouse Gas Emissions Cost and Compliance Model* and its appendices. This report illustrates the concepts and methodologies behind EPA's proposed GHG model. No independent data analysis will be required for this review. Specifically, EPA staff are 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. Toward this end, we ask that you please review and comment on the following items:

1) The overall approach to the specified modeling purpose and the particular methodologies chosen to achieve that purpose;
2) The appropriateness and completeness of the contents of the sample input files. EPA staff are not seeking comment on the particular values of the contents of the input files, which are samples only. These input files are included as Appendices **to the model description:**
   a) The elements of the Market input file, as shown in Appendix 1 of the model description, which characterize the vehicle fleet;
   b) The elements of the Technology input file, in Appendix 2, that constrain the application of technology;
   c) The definition of the standard and economic conditions in the Scenario input file, as shown in Appendix 3;
   d) The elements of the Fuels input file, as shown in Appendix 4, which characterize the fuel types, properties, and prices; and
   e) The reference data contained in Appendix 5 which are currently hard-coded into the model but, in the very near future, will be contained in a user controlled input file.

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 and calculation of compliance;
4) 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.

5) Clarity, completeness and accuracy of the calculations in the Benefits Calculations output file, in which costs and benefits are calculated;
6) Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed; and
7) Recommendations for any functionalities beyond what we have described as "future work."

In making your comments, you should 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. Comments should be sufficiently clear and detailed to allow a thorough understanding by EPA or other parties familiar with the model. EPA requests that you not release the peer review materials or your comments until the Agency makes its model and supporting documentation public. EPA will notify the reviewers when this occurs.

If you have questions about what is required in order to complete this review or need additional background material, please contact Patrick Merritt at 210-522-5422 or pmerritt@swri.org. If you have any questions about the EPA peer review process itself, please contact Ms. Ruth Schenk in EPA's Quality Office, National Vehicle and Fuel Emissions Laboratory by phone (734-214-4017) or through e-mail (schenk.ruth@epa.gov).

With best regards,

Patrick M. Merritt
Senior Research Scientist
Emissions Research and Development Dept.

Attachments (4)

ATTACHMENT 1

EPA Vehicle GHG Emission Cost and Compliance Model Description

Background and Overview

On-road vehicles are the predominant source of GHG emissions from the transportation sector. Of all on-road vehicles, light-duty vehicles and light-duty trucks (hereafter referred to as cars and trucks) produce the majority of the GHG emissions. There are many methods for reducing GHG emissions from cars and trucks due to the myriad of technology options available to improve the efficiency of vehicles. A detailed analysis of the costs and benefits of various GHG emissions reduction requires a specialized application that optimizes and accounts for all the promising technologies, going beyond what can be accomplished with simple spreadsheet tools . Therefore, EPA's Office of Transportation and Air Quality (OTAQ) has developed the Vehicle Greenhouse Gas Emissions Cost and Compliance Model (hereafter referred to as the "EPA model") to help facilitate the analysis of the costs and benefits of reducing GHG emissions from cars and trucks..

Broadly speaking, the EPA model applies technologies with varying degrees of cost and effectiveness to a defined vehicle fleet in order to meet a specified GHG emission target and calculates the costs and benefits of doing so. The technologies are combined into a series of vehicle "packages" over a series of model years, which defines the fleet input file.

The vehicle fleet can be characterized very simplistically (one vehicle) or more precisely (over a thousand vehicle models). Vehicle sales can vary over time in the model. The vehicle description includes the baseline level of GHG emissions along with any other attribute used in setting the target GHG emission level, such as footprint, which is discussed further below.

GHG control technology packages can be applied "one at a time" or in groups or bundles. The costs and effectiveness of these technologies are assumed to be the same for all vehicle models falling within a vehicle type category, such as midsize cars with V6 engines or minivans. The model considers whether a specific vehicle model already has a specific technology package or whether a technology can or cannot be applied to it. The volume of a specific vehicle model's sales which can receive a technology package can be limited by indicating a fraction of its baseline that already contains some effectiveness and cost of each specific technology package. The volume of a given vehicle *type's* sales which can receive a specific technology package can also be limited with a market penetration "cap", if desired. The effectiveness and application limits of each technology package can vary over time, if desired.

Technology is applied to individual vehicles using a ranking process. Within a vehicle type, the order of technology packages is set by the user. Across vehicles, technology is applied to that vehicle with the lowest Technology Application Ranking Factor (hereafter referred to as the TARF). The TARF considers the cost of the technology, the value of any reduced fuel consumption considered by the vehicle purchaser, and the mass of GHG emissions reduced over the life of the vehicle. Fuel costs by calendar year and annual vehicles travelled per vehicle are provided by the user.

Technology is applied to vehicles until all the technologies have reached their caps or until the sales-weighted GHG emission average of a given manufacturer's vehicles complies with the specified GHG emission target or stringency. 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 GHG target can be in the form of a linear or logistic function, which varies the target as a function of vehicle footprint (vehicle track width times wheelbase).

The GHG emission target can vary over time, but not on a model or calendar year basis. One of the fundamental features of the EPA model is that, over a specified vehicle redesign cycle, a manufacturer has the capability to redesign any or all of its vehicles. The EPA model does not attempt to determine exactly which vehicle will be redesigned by each manufacturer in any given model year. Instead, it focuses on the GHG emission goal several model years in the future, reflecting the capability of longer term planning on the part of auto manufacturers. Any need to further restrict the application of technology can be affected through the caps on the application of technology to each vehicle type mentioned above. Approximate costs and benefits of complying with gradually decreasing GHG emission targets within the endpoints of a redesign cycle are produced via linear interpolation, despite that in reality these functions may resemble step functions more closely for any given vehicle.

GHG emission targets are specified in terms of CO2 equivalent emissions. They can simply be CO2 emissions from the tailpipe or a combination of tailpipe CO2 emissions and air conditioner refrigerant emissions. In the case of the latter, the descriptions of vehicles and technologies must include baseline refrigerant emissions and the effectiveness of each technology in reducing these emissions.

Once technology has been added so that every manufacturer meets the specified targets (or exhausts all of the available technologies), average costs per vehicle by manufacturer and industry fleet are determined. Fleet-wide average GHG emissions are also approximated for each calendar year and are used to estimate a wide array of societal costs and benefits associated with the GHG emission control.

The model outputs the costs and the benefits of the control scenario. The primary cost of GHG emission control is the cost of the added technology as compared to the baseline. The primary benefit is the value of reduced fuel consumption and can be sensitive to the user assumed price of fuel. However, the value of a number of other costs and benefits are also evaluated, as listed below:

1) The reduction or co-benefits in VOC, CO, NOx, sulfur dioxide (SOx), and PM emissions associated with reduced fuel production are estimated, as well as their value to society,
2) Societal benefits associated with reduced crude oil use which are not reflected in the price of crude oil,
3) The value of reduced time necessary to refuel vehicles, and
4) The value of GHG emission reductions.

GHG emission control tends to encourage technologies that improve vehicle fuel efficiency and reduces the cost of driving, which in turn can result in more driving. This feedback effect is commonly referred to as the "rebound effect", the extent of which can be specified by the user. Estimates are made of a number of potential costs and benefits associated with driving, as follows:

1) The increase in vehicular VOC, CO, NOx, SOx, and PM emissions,
2) The increased vehicular noise, congestion, and accidents,
3) The value of the increased driving, and
4) The cost of fuel required by the increased driving.

Where the EPA model differs from other similar models is that it adds technology to vehicles on a redesign cycle basis. Some models try to predict the model year when each vehicle model (of hundreds) will be redesigned and then adds technologies to each vehicle on its redesign year. In reality, the timing of vehicle redesign is difficult to predict, because it is constantly adjusting to changes in the market, corporate needs, or government regulations, which these other models are not able to capture. In addition, since there are hundreds of specific vehicle models being sold in any given model year, the technology application process becomes computationally intensive. This methodology creates a situation where the model attempts to achieve a level of precision greater than its accuracy.

The EPA model avoids these two issues by taking a mid to long term approach to vehicle redesign, assuming a 5+ year planning horizon.. In this methodology, the user designates a redesign cycle length (currently this is hard-coded as 5 years, but in the future this will be a user input), and the model redesigns the entire fleet in the final model year of the redesign cycle. This philosophy is based on the assumption that vehicles undergo redesign at a rate consistent throughout the fleet. In addition, the EPA model looks much further into the future than other models, with the capability of adding technology to vehicles over four redesign cycles. Because it is next to impossible to determine each vehicle model's subconfiguration (there are over 1000) 20+ years in the future, the methodology of adding technologies incrementally to each vehicle model by model year does not add value to the model results. Moreover, the EPA model avoids "overmodeling" by allowing for the simplification of the fleet by dozens (or fewer) representative vehicles, rather than the hundreds that are currently forecasted by manufacturers.

Input Files

The EPA model is designed to be flexible in almost every respect. Very little data is hard-coded in the model; since the model relies heavily on its input files, the user can alter them at will to create new vehicle models, types, and technologies, or to change the model's operating parameters for sensitivity analysis or "what-if" scenarios. For example the following can all be modified by the user: vehicle descriptions, the technologies which are available to be applied to each vehicle, as well as their costs and effectiveness.

<u>Vehicle Fleet Characterization</u>

The sample input file, "Market-1", contains a list of the vehicle models that describe the vehicle fleet and five different categories of data that describe them: 1) Vehicle efficiency data, such as baseline fuel economy and GHG emissions (columns N and O); 2) Vehicle attribute data that the model uses in its technology ranking and compliance calculations, such as footprint, weight, and refrigerant type (columns P, Q, and AB respectively); 3) Vehicle attribute data that the model will eventually use when calculating output statistics, such as engine displacement, horsepower, and drive type, although output statistics are not calculated in the current version (columns R, S, and W); 4) Vehicle sales data, which is presented in the form of annual sales in the baseline and in the final "redesign" year of each redesign cycle (columns E through M); 5) An indication of whether a technology package exists in the reference case, and if so, to what degree the technology package effectivenesses and costs are reflected. An example of the Market input file is in Appendix 1.

Reference case technology is tracked to avoid double counting technology costs and GHG improvement. Columns AD through AW represent the fraction of the technology package effectiveness for the different vehicles that is present in the reference case; for example, a value of 35% for technology package 1 means that 35% of the effectiveness of technology package 1 on that vehicle type is already present in the reference case. Columns AY through BQ represent what fraction of the technology packages' cost is reflected in the reference case. Likewise, a value of 75% in any of these columns means that 75% of the technology package's cost on the particular vehicle has been included in the reference case. This is to prevent double counting of technologies that are already in the baselines.

<u>Technology Characterization</u>

EPA designed the model to allow the user to add GHG reducing technologies one at a time or in packages or bundles that would reasonably and likely be added by manufacturers within a redesign cycle. In addition, the user can combine similar vehicle models into "vehicle type" groups which are likely to receive the same list of technology packages. For each vehicle type, the user must rank the technology packages in order of how the EPA model should add them to that specific vehicle type. This approach puts some onus on the user to develop a reasonable sequence of technologies. However, the model also produces information which helps the user determine when a particular technology or bundle of technologies might be “out of order”. The approach also simplifies the model’s calculations and enables synergistic effects among technology packages to be included to the fullest degree possible.

The sample input file entitled “Technology-1” defines the technology packages that are available for the model to add to the fleet. The data in this file can be categorized in three ways: 1) Parameters the model uses to calculate CO2 improvement, such as effectiveness and market penetration cap (the latter being the cap of sales for each vehicle model of a vehicle type that can receive a technology package) (columns D through T); 2) Data the model uses to calculate technology costs, such as the package cost and cost learning coefficients (columns X through AC); 3) Properties of the technology package, such as refrigerant type and fuel type (columns U through W).

Each worksheet in the file contains a user-defined list of technology packages for a different vehicle type. In order to avoid the complexity of synergistic effects, the user must record this list within each worksheet from top to bottom in the order of how the model should add them to the particular vehicle. Since the user defines the technology packages contained in the input file, technologies are dynamic (user defined) and not “hard-coded” within the model. Values in columns L through S represent the Average Incremental Effectiveness (AIE) of the technology package over the previous package (or over the baseline in the case of technology package 1) which the user can adjust on a redesign cycle basis. For example, a value of 7.0% in the AIE column would denote a 7.0% tailpipe CO2 improvement beyond any CO2 improvements already realized. (“Tailpipe CO2” refers to the CO2 emitted over a test cycle - that relates it to vehicle efficiency.) This value of 7% would include any synergistic effects that components of the technology package may have with technologies that have already been added to the vehicle type. Currently, the refrigerant effectiveness noted in column T is based on the fraction reduction in direct refrigerant leakage emissions and is separate from tailpipe CO2. An example of the Technology input file is in Appendix 2.

When technology is sufficiently new, or the leadtime available prior to the end of the redesign cycle is such that it is not reasonable to project that it could be applied to all vehicle models that are of the same specific vehicle type, for example, all minivans, the user can limit its application to minivans through the use of a market cap of less than 100% in columns D through K. This cap can vary by redesign cycle. When a technology package is applied to fewer than 100% of the sales of a vehicle model due to the market cap, the effectiveness of the technology group is simply reduced proportionately to reflect the total net effectiveness of applying that technology package to that vehicle’s sales. The EPA model does not create a new vehicle with the technology package and retain the previous vehicle which did not receive the technology package, splitting sales between the old and new vehicles. If subsequent technology packages can be applied to the vehicle, the user should consider whether in reality the new technology would likely be applied to those vehicles which received the previous technology or those which did not, or a combination of the two. The effectiveness of adding the subsequent technology may depend on which vehicles are receiving it.

Fuel and Energy Prices

The Fuels-1 input file contains data relevant to fuel and electricity, including energy, mass, and carbon density (columns B through D in the Fuel tab), and annual price forecasts for up to 20 years (columns E through X). There is a small subset of fuel information not included in this file that has been hard-coded into the model, which reflects the societal cost of importing fuel, which is discussed briefly below and in the section on benefits calculations. An example of the Fuels-1 file is in Appendix 4.

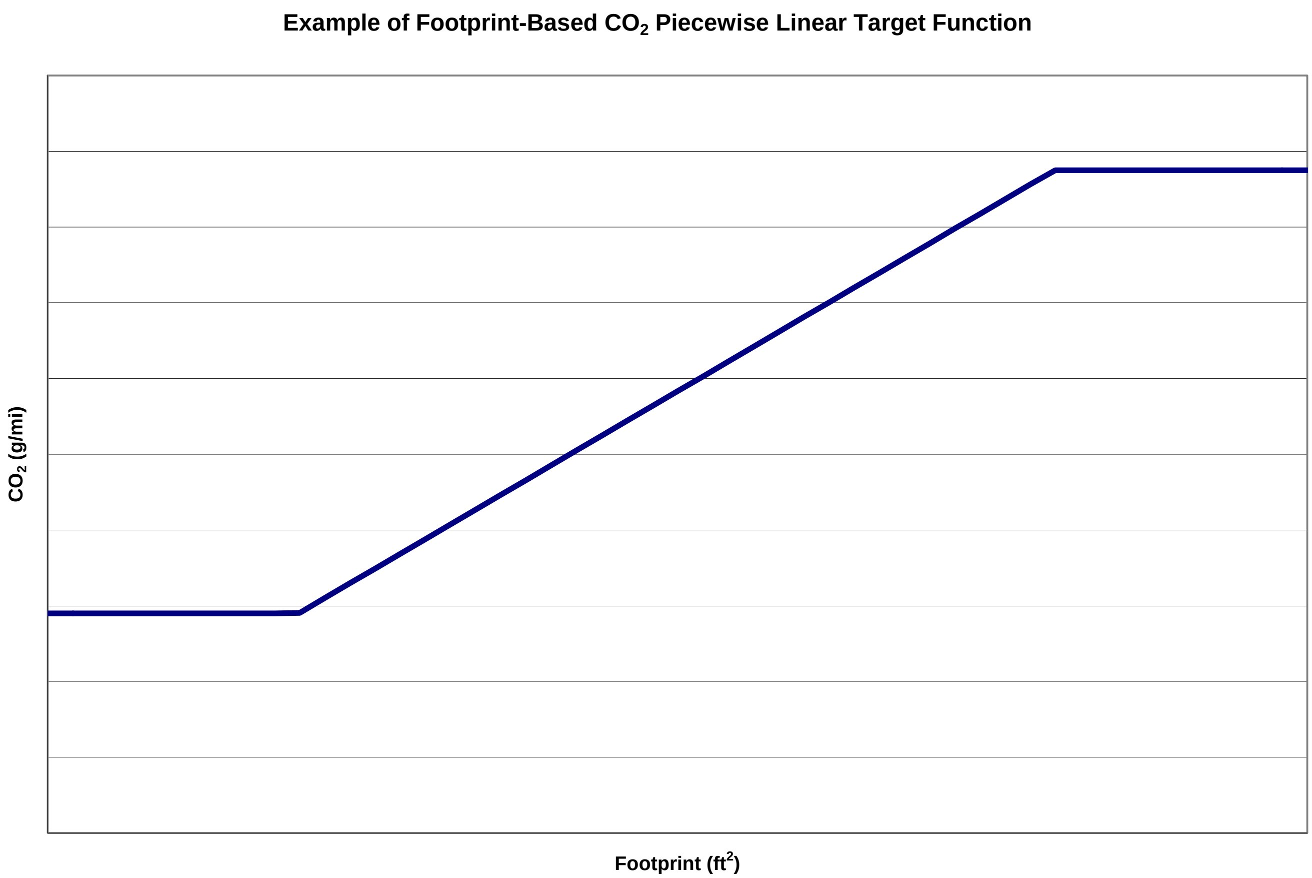
Regulatory Scenarios

The Scenario input file contains all data specifying the number and types of model runs. The Scenarios tab acts as a directory for different model runs, where the user can create an entry for any number of runs that the model can perform in succession. At present, the model is only capable of performing one scenario at a time, but in the future, it will be capable of batch processing. In the Scenarios tab, the user must specify the base year, type of compliance target (CO2 or MPG), type of compliance function (universal = 1, linear attribute = 2, or logistic attribute = 3), the number of redesign cycles, and the names of the other input files that describe the vehicle fleet, technology packages, and fuel properties. At present, the model is limited to a CO2 standard, but our future plans include the capability to analyze an MPG standard as well. These elements are entered in the Scenario input file in columns C through K, and the user can create a name for the run in column B.

As stated above, there are three options for compliance targets. The universal target option is simply a numerical designation which the manufacturers' average fleet CO2 cannot exceed. In contrast, the attribute-based linear target function is described by up to four coefficients and has the following piecewise linear mathematical form:

$$y = \begin{cases} A; x < x_{\min} \\ \dfrac{B - A}{x_{\max} - x_{\min}}[x]; x_{\min} \le x < x_{\max} \\ B; x \ge x_{\max} \end{cases}$$

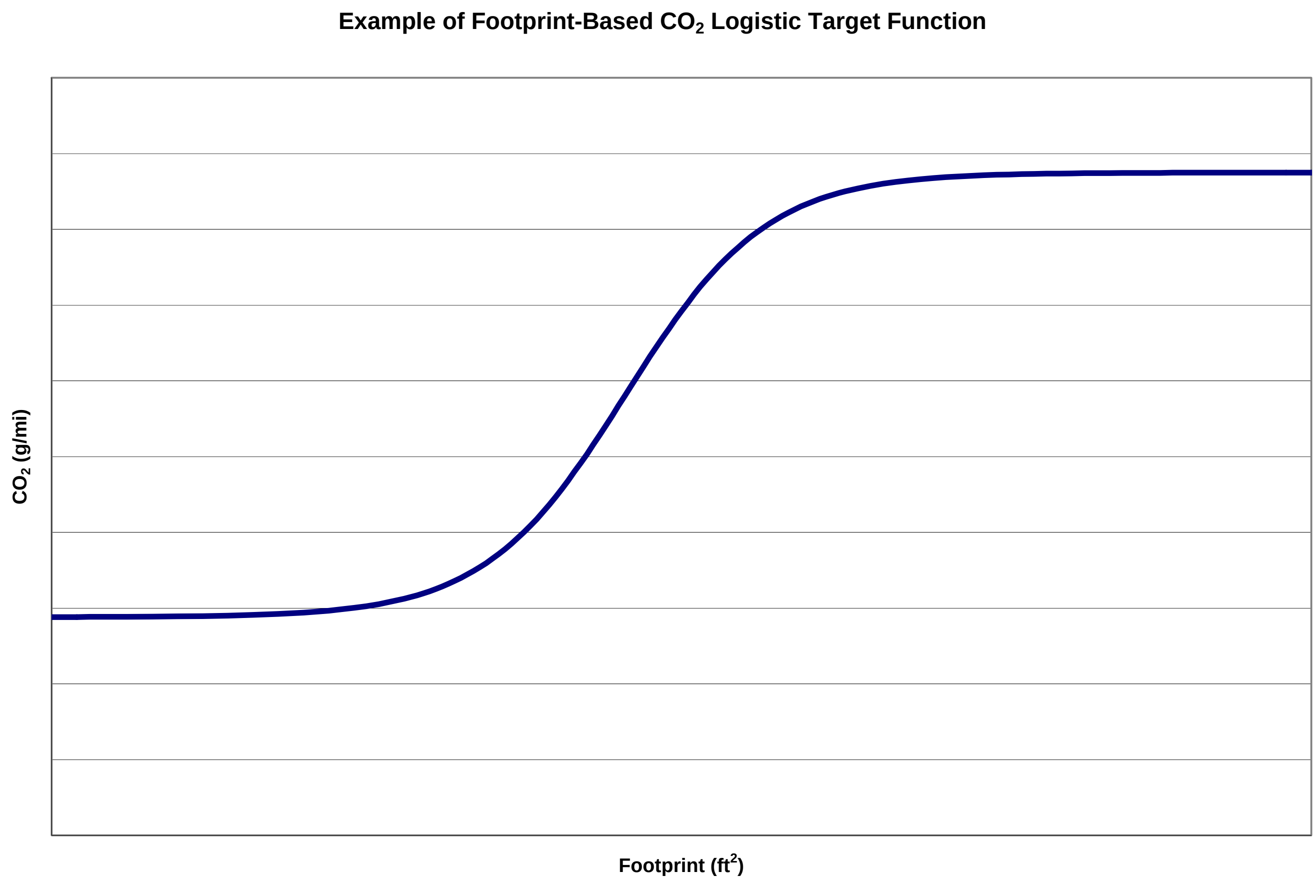
Where A: CO2 minimum
B: CO2 ceiling
x_{min}: Intersection of lower asymptote with slope
x_{max}: Intersection of upper asymptote with slope
x: Vehicle footprint



The footprint-based logistic curve (shown below) is described by four coefficients and has the mathematical form described below.

$$T = A + (B - A)\left(\frac{e^{\frac{x-C}{D}}}{1 - e^{\frac{x-C}{D}}}\right)$$

Where A: CO2 minimum
B: CO2 maximum
C: Midpoint
D: A sort of "inverse slope"
x: Vehicle footprint



The Scenario input file also contains the economic parameters that the model uses to calculate the Technology Application Ranking Factors (TARFs), which are the optimization equations that determine the order of technology application (See the *Model Logic* section below). Such economic data includes the discount rate, vehicle payback period, cafe fine cost, the "gap" between on-road CO2 and test cycle CO2, threshold technology cost (the cost at which manufacturers add technology to only enough vehicles to meet the standard as opposed to adding technology to all of a model line), and the increase in price of CO2 over time. The user enters these economic values into columns B through G in the Economics tab of the Scenario file. An example of the Scenario input file is in Appendix 3.

<u>Input data "hard-coded" into the model</u>

There is a set of data that has been hard-coded into the model in the development phase, which will be moved to a new "References" input file in the very near future. This data is illustrated in Appendix 5 and is comprised of vehicle age data, scrappage rate, vehicle miles travelled, upstream criteria pollutant emissions from fuel/energy production, storage, and distribution, regression coefficients for downstream criteria pollutant emissions, emissions damage cost (cost per ton), economic cost of importing fuel, external costs of driving, and global warming potentials for various GHGs.

Model Operation

Because the model depends so heavily on the input files, the current graphic user interface (GUI) is simple to operate. After installing the program and double clicking on the VGHG icon, click on the file menu and choose "Open," and a window will appear with a set of input files. Click on the sample "Scenario" and it loads the data. The Scenario file indicates which of the other input files are to be used in the run, and a portion of the scenario description is shown in the top box of the GUI. The Market and Technology input files identified in the Scenario file are shown in the two boxes below. When everything is loaded, the car icon turns green. Mouse click on the car button to run the program. In less than a minute, a text file showing the sequence of technology addition by manufacturer and by redesign cycle appears. This file is automatically named Results-"date-time". This file can be saved by the user with a more descriptive name, if desired, by simply using the standard Windows "File", "Save As" actions. There is an additional saved output file entitled "Tarf = "date-time", which includes the results of the TARF calculations for each vehicle type-technology package combination for each redesign cycle. Go back to the file menu in the GUI, and click on "Save," which is necessary to enable the "visualization" function. In the file menu, now click on "visualization" to examine the results of the technology application process for each vehicle model in the market data file. In the near future, the information in the visualization will be generated directly in an output spreadsheet, but at present it is only available in the visualization, and if desired, the user can copy and paste the results manually. Economic costs and benefits can be loaded in a spreadsheet file entitled "Benefits Calculations," located in the "Output" folder. Open the "Benefits Calculations" excel file, and in the "Load" tab, press the "Load" button to get the economic impact results.

Model Logic

The model's programming is organized into three main sections. At first, a pre-processing section reads in the input files and performs intermediate calculations to get the input data into the desired form for calculations in the second section, the "core" calculations. The core model backs out the existing technology from the baseline, and calculates the Technology Application Ranking Factor (the TARF) for each vehicle type-technology package combination and determines the order to which technology packages should be added to vehicles. The core model then adds the effectivenesses and the costs of the technology addition until each manufacturer has met the standard or until all technology packages have been exhausted. Finally, a post-processing section computes the societal costs and benefits of the GHG emissions reduction scenario, including the tons of CO_2 reduced and the gallons of fuel saved and outputs these results in a Microsoft© Excel© file.

Before the model runs the optimization algorithms, a the user can validate the data in the input files, and the model then reads in the data. Each redesign cycle “starts from scratch” in that every vehicle will include only those technologies present in the base year.

The model then executes three time loops in the following order: 1) A calendar year loop that interpolates the annual sales in between redesign cycles; 2) A redesign cycle loop adds technology packages to vehicles until the fleet is in compliance (the “core” programming); 3) A final loop calculates the costs and benefits of the CO2 or MPG program and exports the economic impact results to a Microsoft Excel file (a post processing step).

EPA provided the contractor with the equations and conceptual methodologies for the model with a series of spreadsheets, and the contractor developed the program. These equations and methodologies are outlined after the variable and parameter definitions, below.

<u>Pre-processing:</u>

1) The user can validate the data in the spreadsheets, if desired.
2) Read in the input files
3) Perform calculations to convert input data into useful form for later calculations:

   A) First, the model calculates the annual per-vehicle VMT from the survival fraction and annual miles driven for cars and trucks provided in the Reference file.

$$VMT = SurvivalFraction * AnnualMilesDriven$$

   B) The model then calculates the discounted annual VMT and discounted refrigerant leakage (RCO2) for year 1 through the vehicle’s useful life according to the following equations. The subscript, i, represents the specific year of calculation. DR is the discount rate and IR is the annual increase in value of CO2.

      i. Discounted VMT for fuel savings calculations

$$VMT_{D,FS,i} = VMT_i \times \frac{1+\frac{DR}{2}}{(1+DR)^i}$$

      ii. Discounted VMT for GHG calculations

$$VMT_{D,CO2,i} = VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}$$

iii. Discounted refrigerant leakage

$$\text{RefLeakage}_i = LeakRate_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}$$

C) Finally, the model calculates the approximate per-mile refrigerant leakage emissions in CO2 equivalents from the discounted leakage rate (calculated above), the Global Warming Potential (GWP) of the refrigerant provided in the Reference file, and the discounted VMT (calculated above).

$$RCO2(g/mi) = \frac{\sum_{i=1}^{\substack{Lifetime\\(years)}} \text{RefLeakage}_i \times GWP}{\sum_{i=1}^{\substack{Lifetime\\(years))}} VMT_{D,CO2,i}} = \frac{\sum_{i=1}^{\substack{Lifetime\\(years)}} \left[LeakRate_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right] \times GWP}{\sum_{i=1}^{\substack{Lifetime\\(years)}} \left[VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right]} = \frac{LifetimeLeakage \times GWP}{LifetimeVMT}$$

D) At this point, the model will linearly interpolate the sales in between redesign cycles in order to estimate intermediate annual sales. The final version will incorporate cost learning based on sales volume. Since the current version of the model does not account for cost learning, this calculation is currently performed in the start of the "post processing" section of code, which calculates the social costs and benefits of the modeled regulation, rather than in the core code. Therefore, it will be discussed in the section below on post processing.

<u>Core Program</u>:

The core program is divided into two main parts: The first part determines the order in which the model must add technology packages to vehicle types, and the second part is the technology application until all manufacturers have met the standard provided in the Scenarios input file (or the penetration caps have been met). The core code contains the baseline technology accounting, the technology application ranking optimization, the technology application and cost calculations, and whether the manufacturers have met the standard. Subscripts (t-1) and (t) indicate vehicle conditions before and after technology package "t" addition, respectively.

1) Determine the order of technology application

A) First, the model "backs out" any advanced technology that might have been present in the baseline. This step ensures that costs and benefits aren't double counted when the model is optimizing the order of technology package application. This is done for both Tailpipe and Refrigerant CO2. The subscript, i, refers to the current technology package and the subscript, n is the final technology package for the vehicle type.

$$BackedoutCO2_i = \frac{\prod_i^n CO2_{REF} \times \left(1 - AIE_{i-1}\left(Cap_{i-1} \times TEB_{i-1}\right)\right)}{1 - AIE_i \times \left(Cap_i \times TEB_i\right)}$$

$$BackedoutRCO2_i = \frac{\prod_i^n CO2_{REF} \times \left(1 - RIE_{i-1}\left(Cap_{i-1} \times TEB_{i-1}\right)\right)}{1 - RIE_i \times \left(Cap_i \times TEB_i\right)}$$

whereas AIE is the average incremental effectiveness of the technology package, RIE is the refrigerant incremental effectiveness of the technology package, CAP is the market cap, and TEB is the percent of the technology package's benefit that has been reflected in the baseline. The RIE reflects either a change in refrigerant or a reduction in refrigerant leaks, as opposed to an improvement in A/C efficiency resulting in a fuel efficiency gain (from a smaller compressor, for example) are reflected in the AIE. The backed-out CO2 is calculated for each technology package on each vehicle.

B) Intermediate calculations for each vehicle type-technology package combination:

i. Calculate the new tailpipe and refrigerant CO2 after technology is added to the baseline fleet (any advanced technology in the baseline has been removed via the "backout" calculations) and thus $CO2_{t-1}$ and $RCO2_{t-1}$ are equivalent to the $BackedoutCO2_i$ and $BackedoutRCO2_i$ from above.

$$CO2_t = CO2_{t-1} \times (1 - AIE)$$

$$RCO2_t = RCO2_{t-1} \times (1 - RIE) \times \frac{GWP_t}{GWP_{t-1}}$$

The model uses this "backed out" CO2 in the equations above because it helps compare the effectiveness of the various vehicle-technology package combinations on a level playing field. If the model did not back out the effectiveness of the technology in the baseline, the model would not be able to appropriately compare the effectiveness of the vehicle-technology package combinations, and the technology application order would not be as robust.

ii. Calculate the fuel consumption (FC) before and after technology addition:

$$FC_{t-1} = \frac{CO2_{t-1}}{CD_{t-1} \times \left[\frac{44gCO2}{12gC}\right]}$$

$$FC_{t} = \frac{CO2_{t}}{CD_{t} \times \left[\frac{44gCO2}{12gC}\right]}$$

Whereas CD_{t-1} and CD_t represent the carbon density of the liquid fuel. The model does not use the equation, since it does not account for a change in fuel type. The electric consumption of the vehicle before and after technology addition is a direct input from the Market and Technology file, respectively.

iii. Calculate the fuel savings (FS). Vehicles can have up to two separate energy sources, which are distinguished by subscripts 1 and 2. Currently, the model recognizes the subscript "1" as the liquid fuel and "2" as electricity, for plug-in hybrid vehicles.

$$FS = \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i}\right)_{t-1} - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i}\right)_{t}$$

Since the fuel price (FP) changes from year to year, the fuel savings will be calculated based on the average fuel price from the year of manufacturer to a "Payback Period" (PP), specified by the user.

C) The model then calculates the Technology Application Ranking Factors (TARFs), which are used to compare the effectiveness technology packages on the different vehicle types, and optimize the order in which the model should add technology packages to the fleet. At this point, the model calculates one TARF for every technology package-vehicle type combination.

Currently, there are two TARF equations from which the user can choose: "Effective Cost" and "Cost Effectiveness – Manufacturer."

i. The "Effective Cost" TARF is defined as the cost of the technology (variable plus amortized fixed) minus the discounted fuel savings over a specified payback period of vehicle use minus the implicit reduction in CAFE non-compliance fee. Quantitatively, it is defined as follows:

$$EffCost = TechCost - FS \times \sum_{i=1}^{PP}\left[VMT_{D,FS,i}\right] \times \frac{1}{(1-GAP)} - FEE \times \left(\frac{1}{FC_t} - \frac{1}{FC_{t-1}}\right)$$

Where the GAP is the difference between real-world and test cycle CO2 and the FEE is a fee for non-compliance, both of which are inputs to the model. Appendix 7 contains the full equation form (without intermediate steps).

ii. The Cost Effectiveness-Manufacturer incorporates the effective cost (illustrated above) but also accounts for the GHG benefit. It is defined as the cost of the technology minus the discounted fuel savings over a specified payback period minus the implicit reduction in CAFE non-compliance fee (which is the "effective cost" definition), all divided by the amount of lifetime GHG emission reduction in kg of CO2 equivalent. It is represented quantitatively as the following:

$$CostEff_{MFR} = \frac{TechCost - \sum_{i=1}^{PP}\left[FS_i \times VMT_{D,FS,i}\right] \times \frac{1}{(1-GAP)} - FEE \times \left(\frac{1}{FC_t} - \frac{1}{FC_{t-1}}\right)}{\sum_{i}^{i+35}\left[\left[\left(RCO2_{t-1} - RCO2_1\right) + \left(CO2_{t-1} - CO2_t\right)\right] \times VMT_{D,CO2,i}\right] \times \frac{1}{(1-Gap)}}$$

This equation can be rewritten as:

$$CostEff_{MFR} = \frac{EffCost}{\sum_{i}^{i+35}\left[\left[\left(RCO2_{t-1} - RCO2_1\right) + \left(CO2_{t-1} - CO2_t\right)\right] \times VMT_{D,CO2,i}\right] \times \frac{1}{(1-Gap)}}$$

Appendix 7 contains the full equation form (without intermediate steps).

Finally, the model determines the order in which technology packages are added to vehicles. The model first compares the TARFs corresponding to technology package 1 on all of the different vehicle types in the fleet and chooses the combination with the lowest TARF. (The lowest effective cost/most cost effective combination is represented by the smallest TARF, whereas a negative TARF indicates a negative cost.)

D) Application of technology packages and compliance calculations

At this point, the model has determined the optimal order of technology application and must apply the technologies' effectivenesses and costs until each manufacturer has achieved compliance or exhausted all technology package options.

A) Starting with the vehicle type-technology package combination having the lowest TARF, the model adds the technology package and calculates the new vehicle CO2 emissions according to the following equations:

i. First, the model calculates the tailpipe CO2 (TCO2); i.e., this is the CO2 the vehicle would emit on a test cycle.

$$TCO2_t = \frac{TCO2_{t-1} \times (1 - CAP \times AIE)}{1 - AIE \times TEB}$$

Where TEB is the "Technology Effectiveness Basis," which is the percent of the technology package's effectiveness that is reflected in the baseline for the vehicle to which it is being applied.

ii. The model also calculates the refrigerant CO2 (RCO2), which is based on improvements in leakage or a change in refrigerant

$$RCO2_t = \frac{RCO2_{t-1} \times (1 - CAP \times RIE)}{1 - RIE \times TEB} \times \frac{GWP_t}{GWP_{t-1}}$$

iii. The model must then calculate the cost this technology addition. It calculates average incremental cost, the average per-vehicle cost (averaged over a manufacturer's fleet), and the cumulative cost up to this point for all manufacturers.

The average incremental cost is performed for each technology addition (but is not reported). It is the cost of the technology added up to its market cap minus the cost of the technology present in the baseline.

$$IncrementalCost = TechCost * (CAP - CEB)$$

Where CEB is the "Cost Effectiveness Basis," which is the amount of the technology package's cost that is in the baseline for the particular vehicle.

Next, the average vehicle cost for each manufacturer is calculated and reported.

$$AvgVehicleCost_{MFR} = \left[\frac{TechCost * ModelSales}{TotalFleetSales}\right]_{MFR}$$

The model then updates the cumulative costs of the program. In future versions of the model this can also be expressed in terms of cost per redesign cycle.

$$CumulativeCost_{MFR} = \left(\sum_{T=1}^{Compliance} AvgVehicleCost_{MFR}\right) \times TotalFleetSales_{MFR}$$

whereas T is the number of the technology package.

iv. The next step is to add the tailpipe and refrigerant CO2 equivalent. The result is the vehicle's total CO2 and is used in the calculation for compliance.

$$CO2_t = TCO2_t + RCO2_t$$

B) The model must then recalculate the fleet CO2 for each manufacturer that produces the vehicle type that received the technology package.

$$FleetCO2 = \frac{\sum_{Models}(Sales \times CO2_t)}{\sum_{MFRModels} Sales}$$

The model must calculate this value for each manufacturer and compare the result with the standard that the user has indicated for that manufacturer in the Scenario file input. If the manufacturer has not met the standard, the model iterates back and compares the remaining TARFS for technology package 1 along with the TARF for technology 2 on the same vehicle type to which the previous technology package was just added. The model then repeats the process of choosing the next lowest TARF out of the new group, applying the technology package effectiveness and cost values, calculating the new total CO2, and recalculating the new fleet averages. The model performs this loop until each manufacturer has met the standard or until the technology packages have been exhausted.

Appendix 6 contains a compilation of variable definitions used in this section.

Post-Processing - Calculation of Costs and Benefits

The model estimates discounted costs and benefits on both calendar year and model year bases. We describe these calculations on a calendar year basis first, followed by that for an entire model year's vehicle sales. In both cases, the discount rate is specified by the user, as described above. Except for technology costs, all costs and benefits are estimated on a fleetwide basis. Industry fleetwide technology costs are estimated, but they are also estimated on a disaggregated basis by manufacturer.

Costs and Benefits by Calendar Year

A list of the types of costs and benefits evaluated by the EPA Model was provided in the Background and Overview section above. The first step in estimating these costs and benefits is to develop estimates of vehicle costs, GHG emissions and fuel consumption by model year. This is done by linearly interpolating vehicle sales, the cost of GHG emission control per vehicle, GHG emissions per mile, and fuel consumption per mile between the baseline case and the first redesign cycle and subsequently between redesign cycles. For example, if the baseline year is 2010, redesign year 1 is 2015 and redesign year 2 is 2020, we linearly interpolate between the 2010 and 2015 sales to estimate annual sales for years 2011-2016. Likewise, we linearly interpolate between the 2015 and 2020 sales to estimate annual sales for years 2016-2019. The same is done for the other factors. The following equation depicts the arithmetic involved.

$$AnnualSales_{yearX} = Sales_{yearX-1} + \frac{\left(Sales_{redesignyear2} - Sales_{redesignyear1}\right)}{redesignyear2 - redesignyear1}$$

With an estimated cost per vehicle and vehicle sales by model year, the cost of added technology is simply the product of these two values. For simplicity, we assume that all the sales of a given model year’s vehicles occurs in the calendar year of the same value.

Most of the other costs and benefits depend on an estimation of the amount of VMT occurring in each calendar year by vehicles of a certain model year vintage. As reduced fuel consumption per mile can lead to increased driving, the amount of VMT in the baseline and control cases can differ and increases the complexity of the calculations. Thus, the next step, conceptually, is to estimate the percentage increase in VMT that might result from reduced driving costs.

The rebound effect is defined as the ratio of the percentage change in VMT to the percentage change in incremental driving cost, which is typically assumed to simply the incremental cost of fuel consumed per mile. As mentioned above, the economic concept is that as driving becomes cheaper, people tend to drive more. Since VMT increases with a reduction in fuel consumption, the sign of the rebound effect is negative. The rebound effect (REB) is an input on the “Economics” worksheet of the “Scenario.xls” file. The percentage increase in VMT for a given change in fuel consumption per mile is calculated as follows:

$$\Delta VMT_{reb} = REB * \frac{\left(FleetFC_{old} - FleetFC_{new}\right)}{FleetFC_{old}}$$

Since fuel consumption changes by model year, each model year's vehicles will reflect a different change in VMT. This change in VMT is assumed to continue throughout the life of the vehicle, since fuel economy is assumed to be constant throughout vehicle life.

Only new vehicles are affected by the additional technology. Thus, in any given calendar year, some of the VMT will be by vehicles whose GHG emissions and fuel consumption has changed and the remainder will be by vehicles which were unaffected by the addition of technology. The model estimates this split by predicting each model year's vehicles contribution to total VMT in each calendar year.

The model currently contains estimates of annual VMT per vehicle by vehicle age, as well as the fractions of new vehicles still on the road as a function of age. These estimates are taken from EPA's MOBILE6 model and are contained in cells M1:Q39 of the Shared Inputs worksheet of the Benefits Calculation spreadsheet. The values for these two parameters are currently hard-coded in the model. However, they will soon be made a part of a References spreadsheet and modifiable by the user. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of fuel consumption and VMT-related costs and benefits.

The total VMT by a specific model year's vehicles in specific calendar year is determined by multiplying 1) new vehicle sales for that model year, 2) the fraction of new vehicles remaining on the road according to the age of those vehicles in that calendar year and 3) the annual VMT for that vehicle class at that age. Historic vehicle sales are currently hard-coded in the model, like annual VMT and survival fractions. However, they will soon be made a part of a References spreadsheet and modifiable by the user. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of fuel consumption and VMT-related costs and benefits. Vehicle sales starting with the baseline year are input to the model through the Market spreadsheet, as described above. Historic sales are shown in cells V2:W39 of the Shared Inputs worksheet of the Benefits Calculation spreadsheet. Vehicle sales starting in the baseline year are shown on the Benefits2 (Sales) worksheet of the Benefits Calculation spreadsheet.

These VMT values for each combination of model year and calendar year are then multiplied by fuel consumption per mile and emission factors and summed by calendar year to determine total fuel consumption and emission levels by calendar year both before and after GHG emission control. Fuel consumption per mile and CO2-equivalent emissions before and after control are direct outputs of the compliance model. Pre-control levels are specified in the Market spreadsheet, while post-control values are a direct function of the GHG standard specified. The resultant fuel consumption and emission levels are presented on the Emissions_Fuel_Consv worksheet of the Benefits Calculation spreadsheet. Intermediate calculations are performed on the VMT_Lookup and VMT_Rebound_Effect worksheets of the Benefits Calculation spreadsheet.

The model also estimates the additional emissions of CO, VOC, NOx, PM and SOx which result from the rebound effect. The emission factors for these pollutants are currently hard-coded in the model, like annual VMT and survival fractions. However, they will soon be made a part of a References spreadsheet and modifiable by the user. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of social costs and benefits. These emissions are currently specified as a function of age using either linear or quadratic equations. The coefficients for these emission factors are taken from EPA's MOBILE6 emission model and are shown in cells H1:R11 of the Exclusive Inputs worksheet of the Benefits Calculation spreadsheet. The resultant emission levels are presented on the Emissions_Fuel_Consv worksheet of the Benefits Calculation spreadsheet.

The value of the change in fuel consumption is determined by simply multiplying the change in fuel consumption by calendar year by the price of fuel less taxes. Fuel prices are input to the model via the Fuels spreadsheet, as described above. They are shown in cells D1:E44 of the Shared Inputs worksheet of the Benefits Calculation spreadsheet. Fuel taxes are not currently input to the model, but are simply part of the Benefits Calculation spreadsheet. We plan to add these taxes by fuel type to the Fuels spreadsheet. Fuel taxes are assumed to be constant over time and are shown in cells AE2:AF2 of the VMTAdjCosts worksheet of the Benefits Calculation spreadsheet. The value of fuel savings are shown on column E of the Externaties worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The model also estimates the value of externalities related to crude oil use. These externalities include, for example, monopsony effects within the crude oil market, the economic impact of periodic price shocks, and military costs related to protecting oil production and supply overseas. These values are all in terms of $ per gallon. They are currently hard-coded in the model, like annual VMT and survival fractions. However, they will soon be made a part of a References spreadsheet and modifiable by the user. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of costs and benefits. The value of crude oil related externalities are shown on column F of the Externaties worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The value of the changes in CO2 and other pollutant emissions are based on estimates of the value of these pollutants per ton of emission. The value of CO2 emission reductions is input to the model through the Scenario spreadsheet. This value in real terms can vary over time (e.g., increase at 2.4% per year in real dollars). The values for the other pollutants are currently hard-coded in the model, like annual VMT and survival fractions. However, they will soon be made a part of a References spreadsheet and modifiable by the user. They are shown in cells A15:B23 of the Shared Inputs worksheet of the Benefits Calculation spreadsheet. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of costs and benefits. The value of changes in vehicle emissions are shown on the DownstreamCosts ($) worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The model also estimates the amount of emission reduction related to reduced fuel production and distribution. The estimates of the emissions of each pollutant associated with the production and distribution of each fuel are currently hard-coded in the model, like annual VMT and survival fractions. However, they will soon be made a part of a References spreadsheet and modifiable by the user. They are shown in Columns E and F of the Shared Inputs worksheet of the Benefits Calculation spreadsheet. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of costs and benefits. The value of changes in upstream emissions are shown on the UpstreamCosts ($) worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The model estimates five additional vehicle related costs and benefits. Three are related to the additional VMT resulting from reduced fuel consumption: noise, congestion and accidents. The values for these factors are expressed in terms of $ per mile. Thus, their total values are simply the product of these per mile values and the additional VMT resulting from the reduced fuel consumption. The values of these three vehicle related impacts are currently hard-coded in the model, like annual VMT and survival fractions. However, they will soon be made a part of a References spreadsheet and modifiable by the user. They are shown in cells A11:B14 of the Exclusive Inputs worksheet of the Benefits Calculation spreadsheet. For the purposes of benefit calculation, the user can already change these values in the Benefits Calculation spreadsheet and the changes will flow through to the calculation of costs and benefits. The value of changes in these vehicle impacts on society are shown on the ExternalVMTCosts ($) worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The fourth vehicle related impact is related to the time required to refuel vehicles. As fuel consumption per mile decreases, if fuel tank size doesn’t decrease, or at least does not decrease proportional to fuel consumption, the number of vehicle refuelings will decrease. The parameters involved in estimating the reduction in refuelings are not currently input to the model, but are simply part of the Benefits Calculation spreadsheet. We plan to add these parameters to the References spreadsheet. The value of the reduction in the number of refueling is estimated as the product of:

1) The reduction in fleetwide fuel consumption for a specific calendar year,
2) Average fuel tank size,
3) Average refueling volume, as a percentage of fuel tank capacity,
4) Ratio of the change in fuel tank size to the change in fuel consumtion,
5) Average time required to refuel a vehicle,
6) Value of time to the driver and other occupants,

7) The number of total occupants in the vehicle, including the driver.

The input values and the annual benefits are in columns H and I of the ExternalVMTCosts ($) worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The final vehicle related benefit category is the value of the increased driving associated with the rebound effect. People decide to drive more because the value of travelling somewhere exceeds the cost. This value consists of two components. The first is the sum of the direct costs of the additional driving. This is assumed to be cost of fuel consumed plus that of the additional congestion caused. The additional noise and accidents are not considered to be direct costs. Noise is primarily experienced by non-drivers and therefore not considered by drivers in their decision to take an additional trip. While accidents tend to be proportional to mileage, especially for a given driver, we assume that most of the cost of accidents is borne by insurance, where there is only a weak association with mileage driven. Congestion, on the other hand, is totally experienced by drivers and experienced fully each trip.

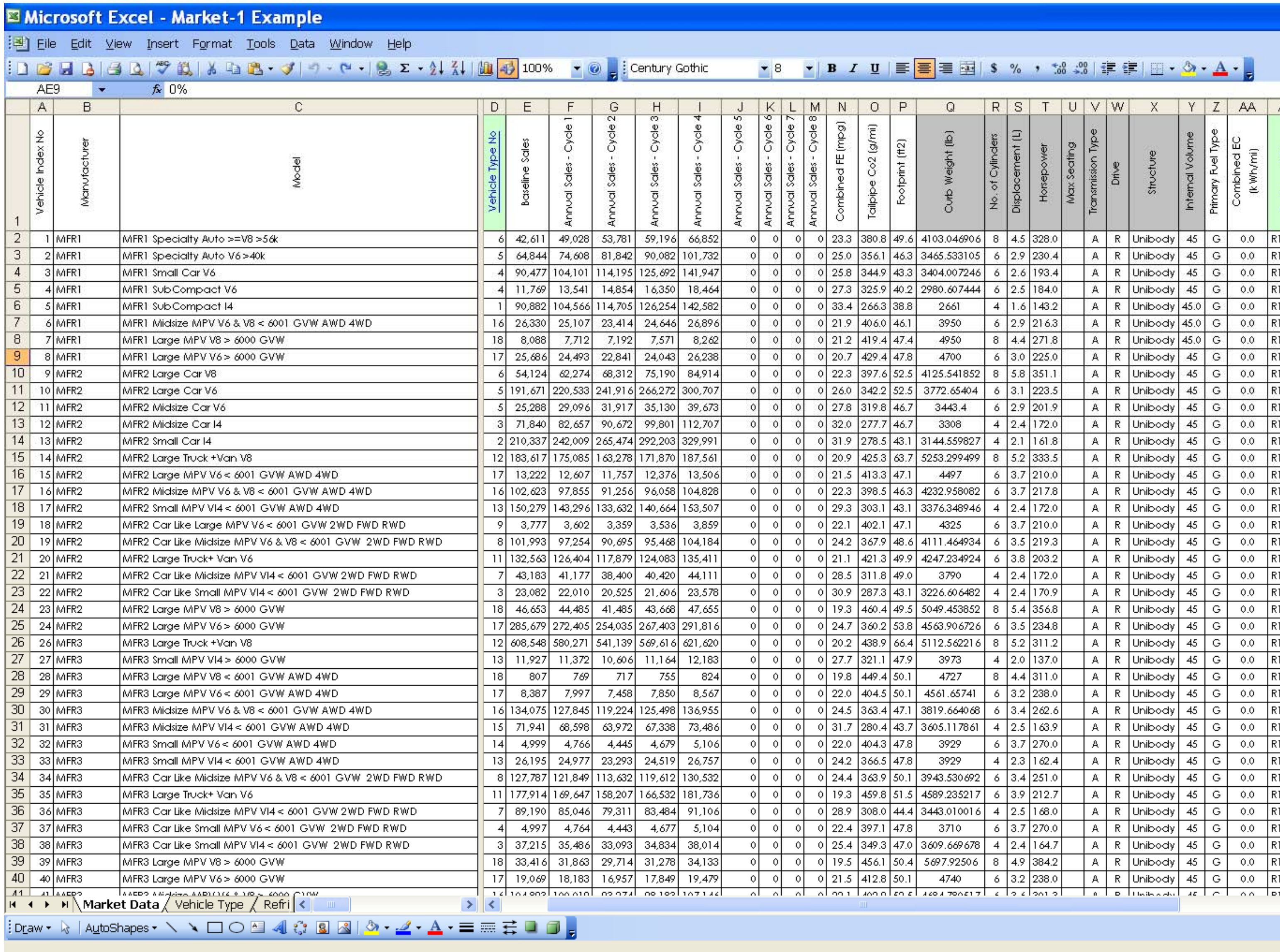
The second component of the value of the additional driving is the change in the consumer surplus of the demand for VMT versus the cost of driving. We estimate this change in surplus as one half the change in VMT times the change in the cost of driving, which here is the reduction in fuel cost per mile. All of these terms have already been estimated for other purposes within the Benefits Calculation spreadsheet. The value of the additional driving is calculated and shown in column I of the ExternalVMTCosts ($) worksheet of the Benefits Calculation spreadsheet, and also carried forward to the Non-Tech Costs and All Costs worksheets.

The first step in loading the Benefits Calculation model is to "save" the results of a model run (click on "File", then "Save" in the menu bar of the model window). This saves the model results in an ".html" file, whose name is the current date/time stamp. The next step is to open the Benefits Calculation spreadsheet (if it is not already opened), go to the Load worksheet, and click on the Load button. From the list of files available to load, choose the last one on the list. This loads the latest model results into the spreadsheet and updates all the cost and benefit estimates.

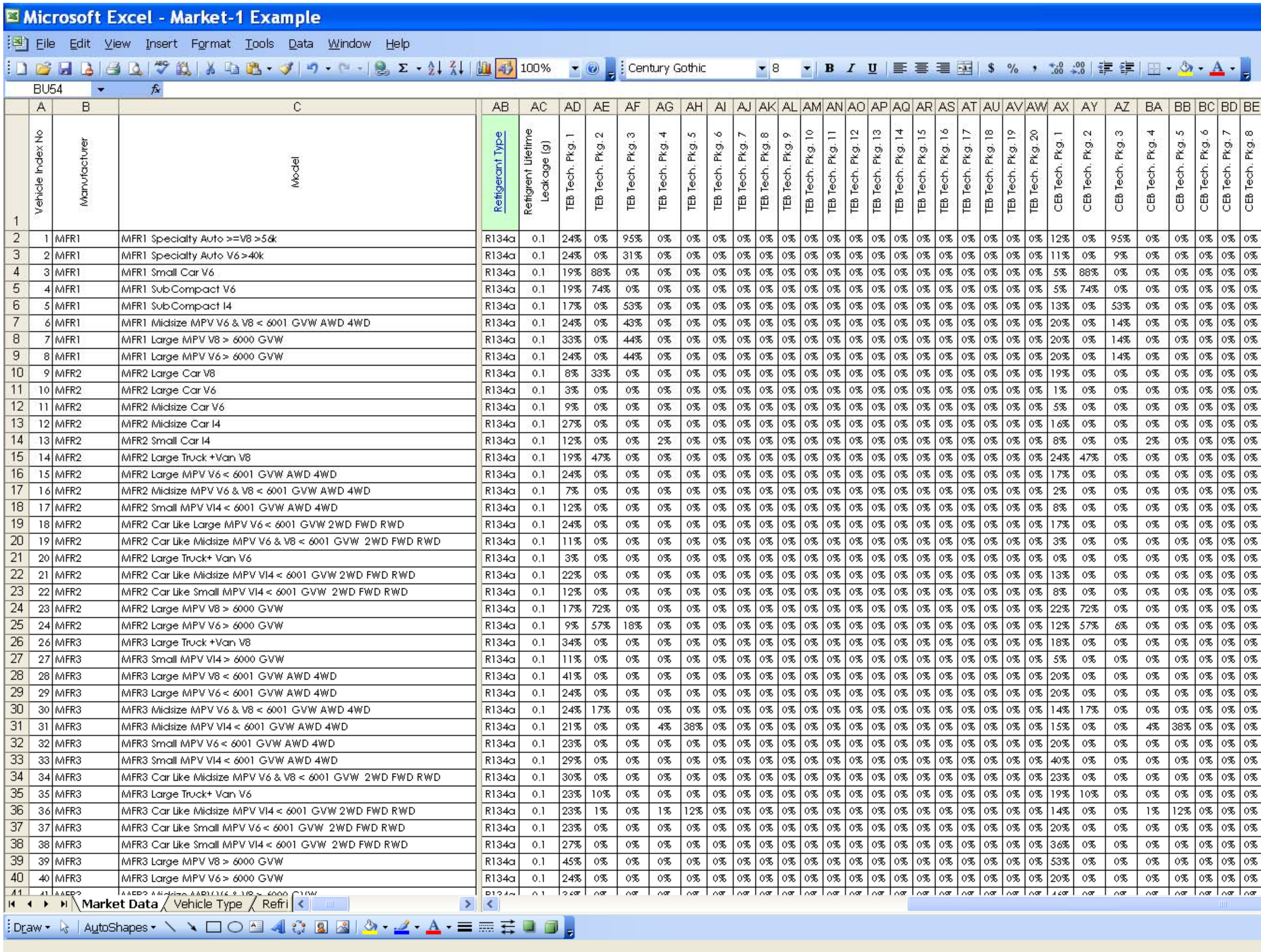
ATTACHMENT 2

Appendices to GHG Model Description

Appendix 1: Examples of Market input file (Vehicle Fleet Characterization)



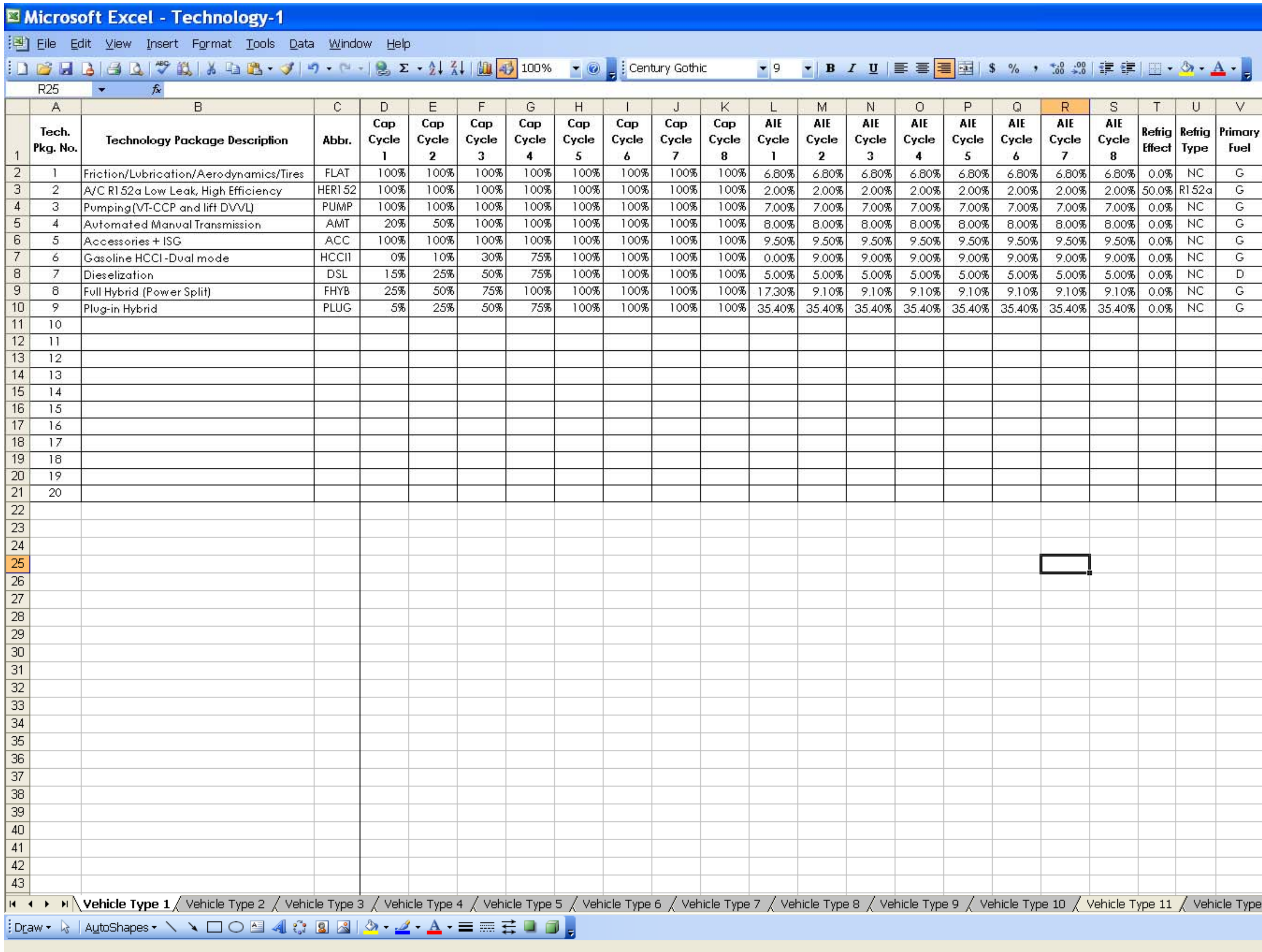
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Vehicle Index No	Manufacturer	Model	Vehicle Type No	Baseline Sales	Annual Sales - Cycle 1	Annual Sales - Cycle 2	Annual Sales - Cycle 3	Annual Sales - Cycle 4	Annual Sales - Cycle 5	Annual Sales - Cycle 6	Annual Sales - Cycle 7	Annual Sales - Cycle 8	Combined FE (mpg)	Tailpipe Co2 (g/mi)	Footprint (ft2)	Curb Weight (lb)	No. of Cylinders	Displacement (L)	Horsepower	Max Seating	Transmission Type	Drive	Structure	Internal Volume	Primary Fuel Type	Combined EC (k Wh/mi)
2	1	MFR1	MFR1 Specialty Auto >=V8 >56k	6	42,611	49,028	53,781	59,196	66,852	0	0	0	0	23.3	380.8	49.6	4103.046906	8	4.5	328.0		A	R	Unibody	45	G	0.0
3	2	MFR1	MFR1 Specialty Auto V6 >40k	5	64,844	74,608	81,842	90,082	101,732	0	0	0	0	25.0	356.1	46.3	3465.533105	6	2.9	230.4		A	R	Unibody	45	G	0.0
4	3	MFR1	MFR1 Small Car V6	4	90,477	104,101	114,195	125,692	141,947	0	0	0	0	25.8	344.9	43.3	3404.007246	6	2.6	193.4		A	R	Unibody	45	G	0.0
5	4	MFR1	MFR1 SubCompact V6	4	11,769	13,541	14,854	16,350	18,464	0	0	0	0	27.3	325.9	40.2	2980.607444	6	2.5	184.0		A	R	Unibody	45	G	0.0
6	5	MFR1	MFR1 SubCompact I4	1	90,882	104,566	114,705	126,254	142,582	0	0	0	0	33.4	266.3	38.8	2661	4	1.6	143.2		A	R	Unibody	45.0	G	0.0
7	6	MFR1	MFR1 Midsize MPV V6 & V8 < 6001 GVW AWD 4WD	16	26,330	25,107	23,414	24,646	26,896	0	0	0	0	21.9	406.0	46.1	3950	6	2.9	216.3		A	R	Unibody	45.0	G	0.0
8	7	MFR1	MFR1 Large MPV V8 > 6000 GVW	18	8,088	7,712	7,192	7,571	8,262	0	0	0	0	21.2	419.4	47.4	4950	8	4.4	271.8		A	R	Unibody	45.0	G	0.0
9	8	MFR1	MFR1 Large MPV V6 > 6000 GVW	17	25,686	24,493	22,841	24,043	26,238	0	0	0	0	20.7	429.4	47.8	4700	6	3.0	225.0		A	R	Unibody	45	G	0.0
10	9	MFR2	MFR2 Large Car V8	6	54,124	62,274	68,312	75,190	84,914	0	0	0	0	22.3	397.6	52.5	4125.541852	8	5.8	351.1		A	R	Unibody	45	G	0.0
11	10	MFR2	MFR2 Large Car V6	5	191,671	220,533	241,916	266,272	300,707	0	0	0	0	26.0	342.2	52.5	3772.65404	6	3.1	223.5		A	R	Unibody	45	G	0.0
12	11	MFR2	MFR2 Midsize Car V6	5	25,288	29,096	31,917	35,130	39,673	0	0	0	0	27.8	319.8	46.7	3443.4	6	2.9	201.9		A	R	Unibody	45	G	0.0
13	12	MFR2	MFR2 Midsize Car I4	3	71,840	82,657	90,672	99,801	112,707	0	0	0	0	32.0	277.7	46.7	3308	4	2.4	172.0		A	R	Unibody	45	G	0.0
14	13	MFR2	MFR2 Small Car I4	2	210,337	242,009	265,474	292,203	329,991	0	0	0	0	31.9	278.5	43.1	3144.559827	4	2.1	161.8		A	R	Unibody	45	G	0.0
15	14	MFR2	MFR2 Large Truck +Van V8	12	183,617	175,085	163,278	171,870	187,561	0	0	0	0	20.9	425.3	63.7	5253.299499	8	5.2	333.5		A	R	Unibody	45	G	0.0
16	15	MFR2	MFR2 Large MPV V6 < 6001 GVW AWD 4WD	17	13,222	12,607	11,757	12,376	13,506	0	0	0	0	21.5	413.3	47.1	4497	6	3.7	210.0		A	R	Unibody	45	G	0.0
17	16	MFR2	MFR2 Midsize MPV V6 & V8 < 6001 GVW AWD 4WD	16	102,623	97,855	91,256	96,058	104,828	0	0	0	0	22.3	398.5	46.3	4232.958082	6	3.7	217.8		A	R	Unibody	45	G	0.0
18	17	MFR2	MFR2 Small MPV VI4 < 6001 GVW AWD 4WD	13	150,279	143,296	133,632	140,664	153,507	0	0	0	0	29.3	303.1	43.1	3376.348946	4	2.4	172.0		A	R	Unibody	45	G	0.0
19	18	MFR2	MFR2 Car Like Large MPV V6 < 6001 GVW 2WD FWD RWD	9	3,777	3,602	3,359	3,536	3,859	0	0	0	0	22.1	402.1	47.1	4325	6	3.7	210.0		A	R	Unibody	45	G	0.0
20	19	MFR2	MFR2 Car Like Midsize MPV V6 & V8 < 6001 GVW 2WD FWD RWD	8	101,993	97,254	90,695	95,468	104,184	0	0	0	0	24.2	367.9	48.6	4111.464934	6	3.5	219.3		A	R	Unibody	45	G	0.0
21	20	MFR2	MFR2 Large Truck+ Van V6	11	132,563	126,404	117,879	124,083	135,411	0	0	0	0	21.1	421.3	49.9	4247.234924	6	3.8	203.2		A	R	Unibody	45	G	0.0
22	21	MFR2	MFR2 Car Like Midsize MPV VI4 < 6001 GVW 2WD FWD RWD	7	43,183	41,177	38,400	40,420	44,111	0	0	0	0	28.5	311.8	49.0	3790	4	2.4	172.0		A	R	Unibody	45	G	0.0
23	22	MFR2	MFR2 Car Like Small MPV VI4 < 6001 GVW 2WD FWD RWD	3	23,082	22,010	20,525	21,606	23,578	0	0	0	0	30.9	287.3	43.1	3226.606482	4	2.4	170.9		A	R	Unibody	45	G	0.0
24	23	MFR2	MFR2 Large MPV V8 > 6000 GVW	18	46,653	44,485	41,485	43,668	47,655	0	0	0	0	19.3	460.4	49.5	5049.453852	8	5.4	356.8		A	R	Unibody	45	G	0.0
25	24	MFR2	MFR2 Large MPV V6 > 6000 GVW	17	285,679	272,405	254,035	267,403	291,816	0	0	0	0	24.7	360.2	53.8	4563.906726	6	3.5	234.8		A	R	Unibody	45	G	0.0
26	26	MFR3	MFR3 Large Truck +Van V8	12	608,548	580,271	541,139	569,616	621,620	0	0	0	0	20.2	438.9	66.4	5112.562216	8	5.2	311.2		A	R	Unibody	45	G	0.0
27	27	MFR3	MFR3 Small MPV VI4 > 6000 GVW	13	11,927	11,372	10,606	11,164	12,183	0	0	0	0	27.7	321.1	47.9	3973	4	2.0	137.0		A	R	Unibody	45	G	0.0
28	28	MFR3	MFR3 Large MPV V8 < 6001 GVW AWD 4WD	18	807	769	717	755	824	0	0	0	0	19.8	449.4	50.1	4727	8	4.4	311.0		A	R	Unibody	45	G	0.0
29	29	MFR3	MFR3 Large MPV V6 < 6001 GVW AWD 4WD	17	8,387	7,997	7,458	7,850	8,567	0	0	0	0	22.0	404.5	50.1	4561.65741	6	3.2	238.0		A	R	Unibody	45	G	0.0
30	30	MFR3	MFR3 Midsize MPV V6 & V8 < 6001 GVW AWD 4WD	16	134,075	127,845	119,224	125,498	136,955	0	0	0	0	24.5	363.4	47.1	3819.664068	6	3.4	262.6		A	R	Unibody	45	G	0.0
31	31	MFR3	MFR3 Midsize MPV VI4 < 6001 GVW AWD 4WD	15	71,941	68,598	63,972	67,338	73,486	0	0	0	0	31.7	280.4	43.7	3605.117861	4	2.5	163.9		A	R	Unibody	45	G	0.0
32	32	MFR3	MFR3 Small MPV V6 < 6001 GVW AWD 4WD	14	4,999	4,766	4,445	4,679	5,106	0	0	0	0	22.0	404.3	47.8	3929	6	3.7	270.0		A	R	Unibody	45	G	0.0
33	33	MFR3	MFR3 Small MPV VI4 < 6001 GVW AWD 4WD	13	26,195	24,977	23,293	24,519	26,757	0	0	0	0	24.2	366.5	47.8	3929	4	2.3	162.4		A	R	Unibody	45	G	0.0
34	34	MFR3	MFR3 Car Like Midsize MPV V6 & V8 < 6001 GVW 2WD FWD RWD	8	127,787	121,849	113,632	119,612	130,532	0	0	0	0	24.4	363.9	50.1	3943.530692	6	3.4	251.0		A	R	Unibody	45	G	0.0
35	35	MFR3	MFR3 Large Truck+ Van V6	11	177,914	169,647	158,207	166,532	181,736	0	0	0	0	19.3	459.8	51.5	4589.235217	6	3.9	212.7		A	R	Unibody	45	G	0.0
36	36	MFR3	MFR3 Car Like Midsize MPV VI4 < 6001 GVW 2WD FWD RWD	7	89,190	85,046	79,311	83,484	91,106	0	0	0	0	28.9	308.0	44.4	3443.010016	4	2.5	168.0		A	R	Unibody	45	G	0.0
37	37	MFR3	MFR3 Car Like Small MPV V6 < 6001 GVW 2WD FWD RWD	4	4,997	4,764	4,443	4,677	5,104	0	0	0	0	22.4	397.1	47.8	3710	6	3.7	270.0		A	R	Unibody	45	G	0.0
38	38	MFR3	MFR3 Car Like Small MPV VI4 < 6001 GVW 2WD FWD RWD	3	37,215	35,486	33,093	34,834	38,014	0	0	0	0	25.4	349.3	47.0	3609.669678	4	2.4	164.7		A	R	Unibody	45	G	0.0
39	39	MFR3	MFR3 Large MPV V8 > 6000 GVW	18	33,416	31,863	29,714	31,278	34,133	0	0	0	0	19.5	456.1	50.4	5697.92506	8	4.9	384.2		A	R	Unibody	45	G	0.0
40	40	MFR3	MFR3 Large MPV V6 > 6000 GVW	17	19,069	18,183	16,957	17,849	19,479	0	0	0	0	21.5	412.8	50.1	4740	6	3.2	238.0		A	R	Unibody	45	G	0.0



	Vehicle Index No	Manufacturer	Model	Refrigerant Type	Refrigent Lifetime Leakage (g)	TEB Tech. Pkg. 1	TEB Tech. Pkg. 2	TEB Tech. Pkg. 3	TEB Tech. Pkg. 4	TEB Tech. Pkg. 5	TEB Tech. Pkg. 6	TEB Tech. Pkg. 7	TEB Tech. Pkg. 8	TEB Tech. Pkg. 9	TEB Tech. Pkg. 10	TEB Tech. Pkg. 11	TEB Tech. Pkg. 12	TEB Tech. Pkg. 13	TEB Tech. Pkg. 14	TEB Tech. Pkg. 15	TEB Tech. Pkg. 16	TEB Tech. Pkg. 17	TEB Tech. Pkg. 18	TEB Tech. Pkg. 19	TEB Tech. Pkg. 20	CEB Tech. Pkg. 1	CEB Tech. Pkg. 2	CEB Tech. Pkg. 3	CEB Tech. Pkg. 4	CEB Tech. Pkg. 5	CEB Tech. Pkg. 6	CEB Tech. Pkg. 7	CEB Tech. Pkg. 8
	A	B	C	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE
2	1	MFR1	MFR1 Specialty Auto >=V8 >56k	R134a	0.1	24%	0%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	12%	0%	95%	0%	0%	0%	0%	0%
3	2	MFR1	MFR1 Specialty Auto V6>40k	R134a	0.1	24%	0%	31%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	0%	9%	0%	0%	0%	0%	0%
4	3	MFR1	MFR1 Small Car V6	R134a	0.1	19%	88%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	88%	0%	0%	0%	0%	0%	0%
5	4	MFR1	MFR1 SubCompact V6	R134a	0.1	19%	74%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	74%	0%	0%	0%	0%	0%	0%
6	5	MFR1	MFR1 SubCompact I4	R134a	0.1	17%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	0%	53%	0%	0%	0%	0%	0%
7	6	MFR1	MFR1 Midsize MPV V6 & V8 < 6001 GVW AWD 4WD	R134a	0.1	24%	0%	43%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	14%	0%	0%	0%	0%	0%
8	7	MFR1	MFR1 Large MPV V8 > 6000 GVW	R134a	0.1	33%	0%	44%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	14%	0%	0%	0%	0%	0%
9	8	MFR1	MFR1 Large MPV V6 > 6000 GVW	R134a	0.1	24%	0%	44%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	14%	0%	0%	0%	0%	0%
10	9	MFR2	MFR2 Large Car V8	R134a	0.1	8%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%	0%	0%	0%	0%	0%	0%	0%
11	10	MFR2	MFR2 Large Car V6	R134a	0.1	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
12	11	MFR2	MFR2 Midsize Car V6	R134a	0.1	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%
13	12	MFR2	MFR2 Midsize Car I4	R134a	0.1	27%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%	0%	0%	0%	0%
14	13	MFR2	MFR2 Small Car I4	R134a	0.1	12%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	2%	0%	0%	0%	0%
15	14	MFR2	MFR2 Large Truck +Van V8	R134a	0.1	19%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	24%	47%	0%	0%	0%	0%	0%	0%
16	15	MFR2	MFR2 Large MPV V6 < 6001 GVW AWD 4WD	R134a	0.1	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0%	0%
17	16	MFR2	MFR2 Midsize MPV V6 & V8 < 6001 GVW AWD 4WD	R134a	0.1	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%
18	17	MFR2	MFR2 Small MPV VI4 < 6001 GVW AWD 4WD	R134a	0.1	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%	0%	0%
19	18	MFR2	MFR2 Car Like Large MPV V6 < 6001 GVW 2WD FWD RWD	R134a	0.1	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0%	0%
20	19	MFR2	MFR2 Car Like Midsize MPV V6 & V8 < 6001 GVW 2WD FWD RWD	R134a	0.1	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%
21	20	MFR2	MFR2 Large Truck+ Van V6	R134a	0.1	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22	21	MFR2	MFR2 Car Like Midsize MPV VI4 < 6001 GVW 2WD FWD RWD	R134a	0.1	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	0%	0%	0%	0%	0%	0%	0%
23	22	MFR2	MFR2 Car Like Small MPV VI4 < 6001 GVW 2WD FWD RWD	R134a	0.1	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%	0%	0%
24	23	MFR2	MFR2 Large MPV V8 > 6000 GVW	R134a	0.1	17%	72%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	22%	72%	0%	0%	0%	0%	0%	0%
25	24	MFR2	MFR2 Large MPV V6 > 6000 GVW	R134a	0.1	9%	57%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	12%	57%	6%	0%	0%	0%	0%	0%
26	26	MFR3	MFR3 Large Truck +Van V8	R134a	0.1	34%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	18%	0%	0%	0%	0%	0%	0%	0%
27	27	MFR3	MFR3 Small MPV VI4 > 6000 GVW	R134a	0.1	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%
28	28	MFR3	MFR3 Large MPV V8 < 6001 GVW AWD 4WD	R134a	0.1	41%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%
29	29	MFR3	MFR3 Large MPV V6 < 6001 GVW AWD 4WD	R134a	0.1	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%
30	30	MFR3	MFR3 Midsize MPV V6 & V8 < 6001 GVW AWD 4WD	R134a	0.1	24%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%	17%	0%	0%	0%	0%	0%	0%
31	31	MFR3	MFR3 Midsize MPV VI4 < 6001 GVW AWD 4WD	R134a	0.1	21%	0%	0%	4%	38%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%	0%	0%	4%	38%	0%	0%	0%
32	32	MFR3	MFR3 Small MPV V6 < 6001 GVW AWD 4WD	R134a	0.1	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%
33	33	MFR3	MFR3 Small MPV VI4 < 6001 GVW AWD 4WD	R134a	0.1	29%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	40%	0%	0%	0%	0%	0%	0%	0%
34	34	MFR3	MFR3 Car Like Midsize MPV V6 & V8 < 6001 GVW 2WD FWD RWD	R134a	0.1	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	23%	0%	0%	0%	0%	0%	0%	0%
35	35	MFR3	MFR3 Large Truck+ Van V6	R134a	0.1	23%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%	10%	0%	0%	0%	0%	0%	0%
36	36	MFR3	MFR3 Car Like Midsize MPV VI4 < 6001 GVW 2WD FWD RWD	R134a	0.1	23%	1%	0%	1%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%	0%	0%	1%	12%	0%	0%	0%
37	37	MFR3	MFR3 Car Like Small MPV V6 < 6001 GVW 2WD FWD RWD	R134a	0.1	23%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%
38	38	MFR3	MFR3 Car Like Small MPV VI4 < 6001 GVW 2WD FWD RWD	R134a	0.1	27%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	36%	0%	0%	0%	0%	0%	0%	0%
39	39	MFR3	MFR3 Large MPV V8 > 6000 GVW	R134a	0.1	45%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%
40	40	MFR3	MFR3 Large MPV V6 > 6000 GVW	R134a	0.1	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%

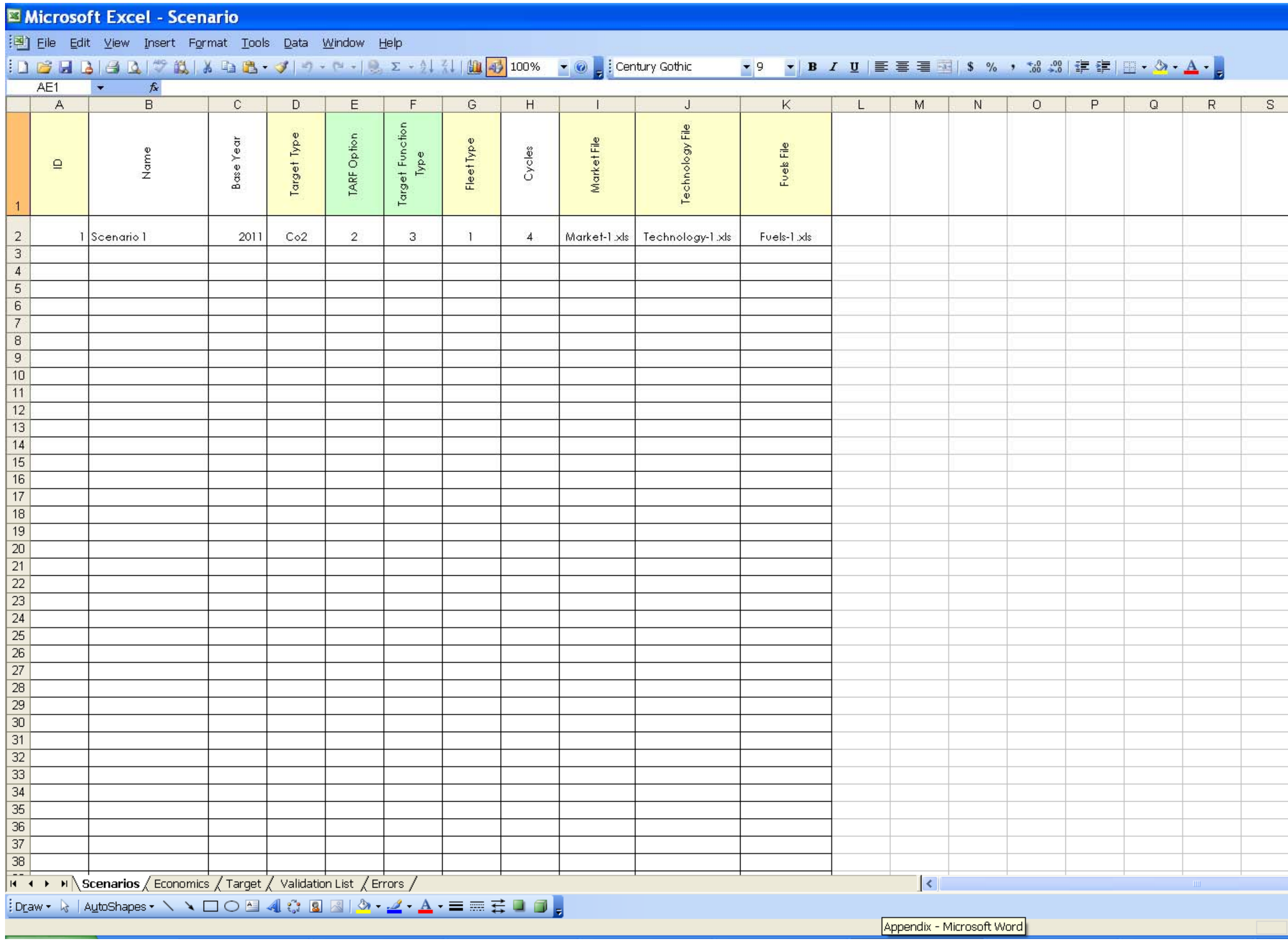
1

Appendix 2: Technology input file (technology package characterization)

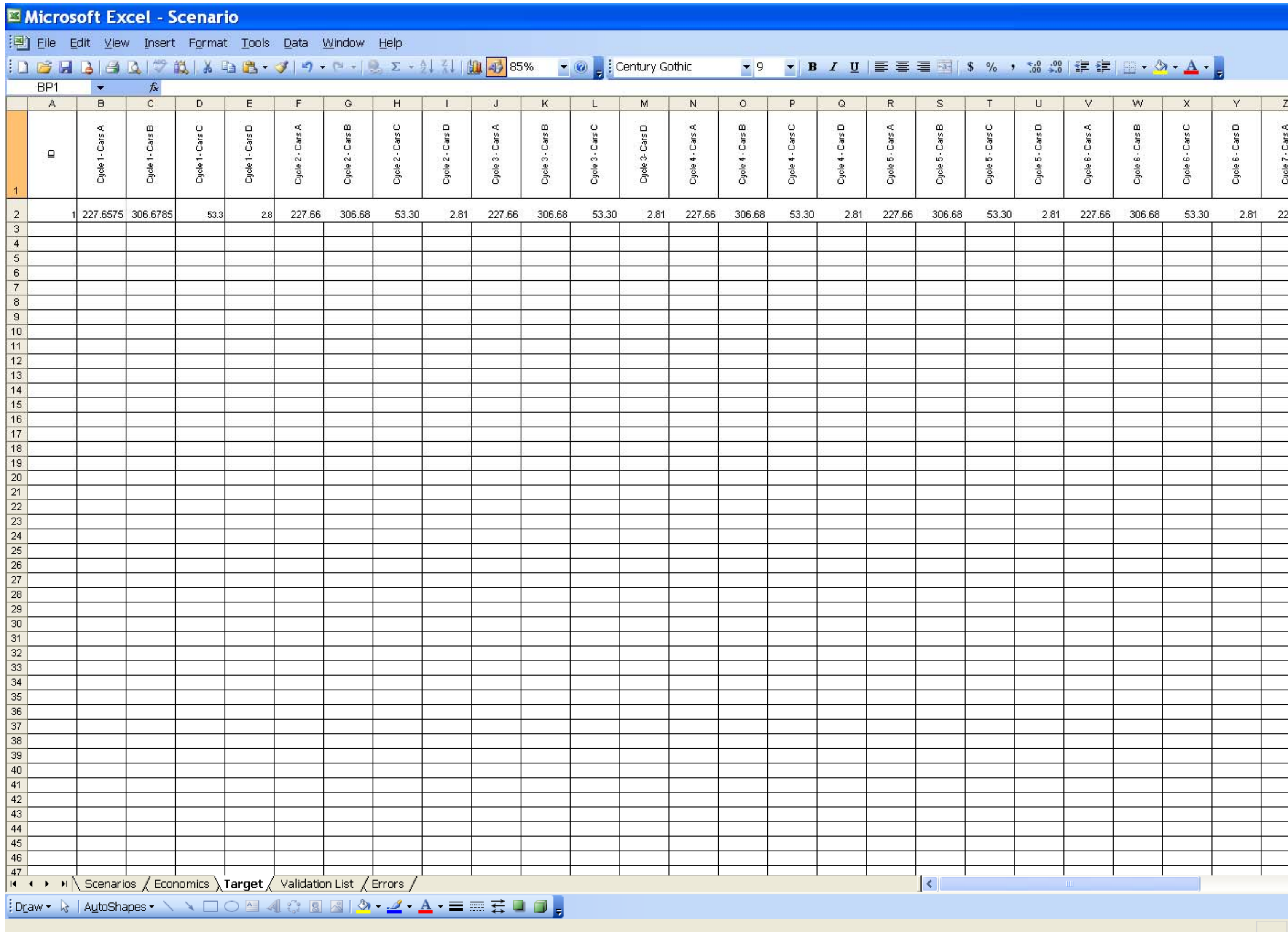


Tech. Pkg. No.	Technology Package Description	Abbr.	Cap Cycle 1	Cap Cycle 2	Cap Cycle 3	Cap Cycle 4	Cap Cycle 5	Cap Cycle 6	Cap Cycle 7	Cap Cycle 8	AIE Cycle 1	AIE Cycle 2	AIE Cycle 3	AIE Cycle 4	AIE Cycle 5	AIE Cycle 6	AIE Cycle 7	AIE Cycle 8	Refrig Effect	Refrig Type	Primary Fuel
1	Friction/Lubrication/Aerodynamics/Tires	FLAT	100%	100%	100%	100%	100%	100%	100%	100%	6.80%	6.80%	6.80%	6.80%	6.80%	6.80%	6.80%	6.80%	0.0%	NC	G
2	A/C R152a Low Leak, High Efficiency	HER152	100%	100%	100%	100%	100%	100%	100%	100%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	50.0%	R152a	G
3	Pumping(VT-CCP and lift DVVL)	PUMP	100%	100%	100%	100%	100%	100%	100%	100%	7.00%	7.00%	7.00%	7.00%	7.00%	7.00%	7.00%	7.00%	0.0%	NC	G
4	Automated Manual Transmission	AMT	20%	50%	100%	100%	100%	100%	100%	100%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	0.0%	NC	G
5	Accessories + ISG	ACC	100%	100%	100%	100%	100%	100%	100%	100%	9.50%	9.50%	9.50%	9.50%	9.50%	9.50%	9.50%	9.50%	0.0%	NC	G
6	Gasoline HCCI -Dual mode	HCCI1	0%	10%	30%	75%	100%	100%	100%	100%	0.00%	9.00%	9.00%	9.00%	9.00%	9.00%	9.00%	9.00%	0.0%	NC	G
7	Dieselization	DSL	15%	25%	50%	75%	100%	100%	100%	100%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	0.0%	NC	D
8	Full Hybrid (Power Split)	FHYB	25%	50%	75%	100%	100%	100%	100%	100%	17.30%	9.10%	9.10%	9.10%	9.10%	9.10%	9.10%	9.10%	0.0%	NC	G
9	Plug-in Hybrid	PLUG	5%	25%	50%	75%	100%	100%	100%	100%	35.40%	35.40%	35.40%	35.40%	35.40%	35.40%	35.40%	35.40%	0.0%	NC	G
10																					
11																					
12																					
13																					
14																					
15																					
16																					
17																					
18																					
19																					
20																					

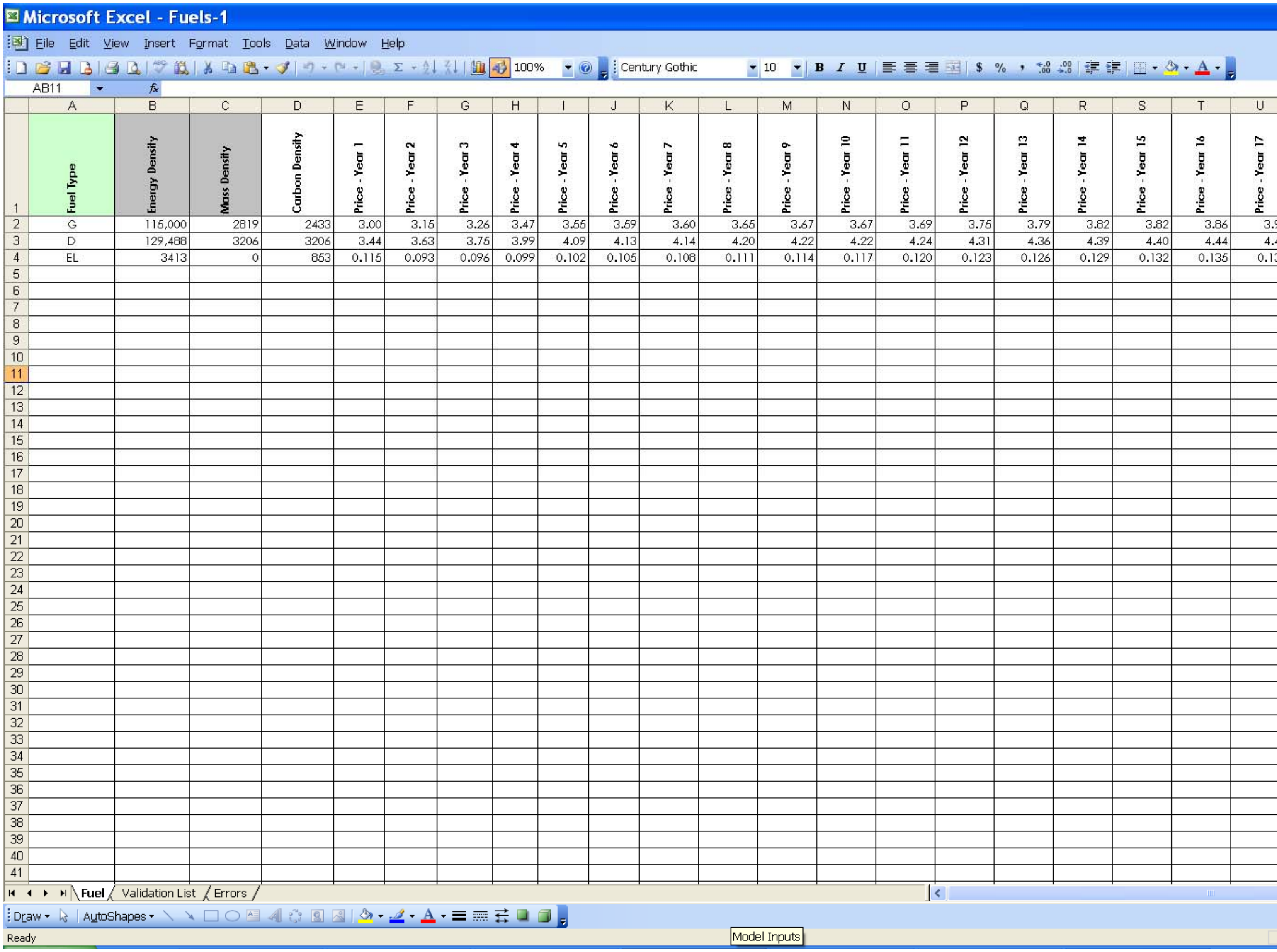
Appendix 3: Scenario input file


Microsoft Excel - Scenario
File Edit View Insert Format Tools Data Window Help
100%
Century Gothic
9
AE1
ID
Name
Base Year
Target Type
TARF Option
Target Function Type
Fleet Type
Cycles
Market File
Technology File
Fuels File
1
Scenario 1
2011
Co2
2
3
1
4
Market-1.xls
Technology-1.xls
Fuels-1.xls
Scenarios
Economics
Target
Validation List
Errors
Draw
AutoShapes
Appendix - Microsoft Word

1


Microsoft Excel - Scenario
File Edit View Insert Format Tools Data Window Help
85%
Century Gothic
9
BP1
ID
Cycle 1 - Cars A
Cycle 1 - Cars B
Cycle 1 - Cars C
Cycle 1 - Cars D
Cycle 2 - Cars A
Cycle 2 - Cars B
Cycle 2 - Cars C
Cycle 2 - Cars D
Cycle 3 - Cars A
Cycle 3 - Cars B
Cycle 3 - Cars C
Cycle 3 - Cars D
Cycle 4 - Cars A
Cycle 4 - Cars B
Cycle 4 - Cars C
Cycle 4 - Cars D
Cycle 5 - Cars A
Cycle 5 - Cars B
Cycle 5 - Cars C
Cycle 5 - Cars D
Cycle 6 - Cars A
Cycle 6 - Cars B
Cycle 6 - Cars C
Cycle 6 - Cars D
Cycle 7 - Cars A
1 227.6575 306.6785 53.3 2.8 227.66 306.68 53.30 2.81 227.66 306.68 53.30 2.81 227.66 306.68 53.30 2.81 227.66 306.68 53.30 2.81 227.66 306.68 53.30 2.81
Scenarios
Economics
Target
Validation List
Errors
Draw
AutoShapes

Appendix 4: Fuels input file



Fuel Type	Energy Density	Mass Density	Carbon Density	Price - Year 1	Price - Year 2	Price - Year 3	Price - Year 4	Price - Year 5	Price - Year 6	Price - Year 7	Price - Year 8	Price - Year 9	Price - Year 10	Price - Year 11	Price - Year 12	Price - Year 13	Price - Year 14	Price - Year 15	Price - Year 16	Price - Year 17
G	115,000	2819	2433	3.00	3.15	3.26	3.47	3.55	3.59	3.60	3.65	3.67	3.67	3.69	3.75	3.79	3.82	3.82	3.86	3.9
D	129,488	3206	3206	3.44	3.63	3.75	3.99	4.09	4.13	4.14	4.20	4.22	4.22	4.24	4.31	4.36	4.39	4.40	4.44	4.4
EL	3413	0	853	0.115	0.093	0.096	0.099	0.102	0.105	0.108	0.111	0.114	0.117	0.120	0.123	0.126	0.129	0.132	0.135	0.13

Appendix 5: Tables of hard-coded input data, which will soon be included in an editable input file.

Downstream Criteria Pollutant Emissions					
	Regression Coefficients				
	CO		VOC		NOx
	LDV	LDT	LDV	LDT	LDV
a	4.5689	3.315	0.0980	0.1429	0.0008
b	1.5073	1.3852	-0.0052	-0.0054	0.0275
c			0.0030	0.0033	0.0262

y = b*[x] + a

y = c*[x2] + b*[x] + a

Upstream Emissions from Fuel/Energy Production, Storage, and Distribution		
Pollutant	Fuel Type	Total Upstream Emissions (grams/mmBtu)
CO	Conventional Gasoline	14.45
	Low Sulfur Diesel	12.67
	Electricity Generation	58.55
VOC	Conventional Gasoline	27.42
	Low Sulfur Diesel	7.78
	Electricity Generation	19.73
NOx	Conventional Gasoline	48.11
	Low Sulfur Diesel	42.92
	Electricity Generation	239.85
PM2.5	Conventional Gasoline	4.30
	Low Sulfur Diesel	3.48
	Electricity Generation	76.31
SOx	Conventional Gasoline	24.13
	Low Sulfur Diesel	20.94
	Electricity Generation	527.33
CO2	Conventional Gasoline	17067
	Low Sulfur Diesel	15560
	Electricity Generation	219933

	Average CO2 emissions (gpm)		New Vehicle Sales	
Model Year	Cars	Trucks	Cars	Trucks
2010	364	514	8100000	6300000
2009	365	514	8000000	6700000
2008	365	517	7919000	7020000
2007	365	518	7885000	7290000
2006	366	519	8130000	6932000
2005	365	519	7964000	7886000
2004	365	523	7538000	8173000
2003	366	524	7951000	7824000
2002	366	519	8304000	7815000
2001	366	520	8408000	7202000
2000	360	494	9128000	7447000
1999	360	495	8379000	6839000
1998	357	495	7972000	6485000
1997	356	496	8335000	6124000
1996	362	458	7890000	5254000
1995	358	465	9396000	5749000
1994	362	456	8415000	5710000
1993	358	457	8456000	4754000
1992	364	453	8108000	4064000
1991	355	447	8524000	4049000
1990	375	483	8810000	3805000
1989	375	497	10018000	4435000
1988	372	510	10736000	4559000
1987	375	538	10731000	4134000
1986	381	463	11015000	4350000
1985	436	513	10791000	3669000
1984	443	497	10675000	3345000
1983	456	799	8002000	2300000
1982	446	956	7819000	1914000
1981	455	593	8733000	1821000
1980	538	1088	9443000	1863000
1979	616	1197	10794000	3088000
1978	646	1245	11175000	3273000
1977	661	1027	11300000	2823000
1976	691	1124	9722000	2612000
1975	698	1124	8237000	1987000

Vehicle Age Data				
Vehicle Age	Proportion of Original Sales Surviving to Age:		Average Annual Miles Driven	
	Car	Truck	Car	Truck
1	0.9950	0.9950	13,389	15,133
2	0.9900	0.9741	13,135	14,849
3	0.9831	0.9603	12,860	14,529
4	0.9731	0.9420	12,567	14,178
5	0.9593	0.9190	12,257	13,799
6	0.9413	0.8590	11,933	13,396
7	0.9188	0.8226	11,596	12,974
8	0.8918	0.7827	11,248	12,535
9	0.8604	0.7401	10,893	12,084
10	0.8252	0.6956	10,531	11,625
11	0.7866	0.6956	10,165	11,161
12	0.7170	0.6501	9,797	10,697
13	0.6125	0.6042	9,429	10,235
14	0.5094	0.5517	9,063	9,781
15	0.4142	0.5009	8,702	9,337
16	0.3308	0.4522	8,346	8,908
17	0.2604	0.4062	7,999	8,498
18	0.2028	0.3633	7,662	8,109
19	0.1565	0.3236	7,337	7,747
20	0.1200	0.2873	7,028	7,415
21	0.0916	0.2542	6,734	7,117
22	0.0696	0.2244	6,459	6,857
23	0.0527	0.1975	6,206	6,638
24	0.0399	0.1735	5,974	6,464
25	0.0301	0.1522	5,768	6,340
26	0.0227	0.1332	5,589	6,269
27	0.0000	0.1165	5,438	6,254
28	0.0000	0.1017	5,319	6,254
29	0.0000	0.0887	5,233	6,254
30	0.0000	0.0773	5,182	6,254
31	0.0000	0.0673	5,182	6,254
32	0.0000	0.0586	5,182	6,254
33	0.0000	0.0509	5,182	6,254
34	0.0000	0.0443	5,182	6,254
35	0.0000	0.0385	5,182	6,254
36	0.0000	0.0334	5,182	6,254

Appendix 6: Definitions of variables in Model Equations

RIE = *refrigerant incremental effectiveness of the technology package on that vehicle type*
$CO2_{t-1}$ = *tailpipe CO2 emissions before technology addition*
$CO2_t$ = *tailpipe CO2 emissions after technology addition*
GWP_{t-1} = *global warming potential of the refrigerant before technology addition*
GWP_t = *global warming potential of the refrigerant after technology addition*
CD_{t-1} = *carbon density of fuel before technology addition*
CD_t = *carbon density of fuel after technology addition*
FC_{t-1} = *fuel applicable to prior technology*
FC_t = *fuel applicable to new technology*

DR = *discount rate*
IR = *annual increase in value of* CO_2
PP = *payback period*
FEE = *fine for non-compliance (CAFE)*
GAP = *difference between test-cycle fuel economy and real-world fuel economy*
VMT_i = *annual miles traveled in year i*
$VMT_{D,FS,i}$ = *annual miles traveled in year i, discounted*
$VMT_{D,CO2,i}$ = *annual miles traveled in year i, discounted*
$RCO2_i$ = *refrigerant leakage rate in year i (g/mi)*
$RCO2_{t-1}$ = *refrigerant leakage before technology addition*
$RCO2_t$ = *refrigerant leakage after technology addition*
TCO2 = *tailpipe CO2 (e.g., the test cycle CO2 emissions)*
REB = *rebound coefficient (% change in VMT for every 1% change in fuel consumption)*
TEB = *technology effectiveness basis, which is the effectiveness of the technology package reflected in the baseline*
CEB = *cost effectiveness basis, which is the cost of the technology package reflected in the baseline*

Appendix 7: TARF Equations (full)

$$EffCost = TechCost - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i} \right)_{t-1} - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i} \right) \times \sum_{i=1}^{PP} \left[VMT_{D,FS,i} \right] \times \frac{1}{(1 - GAP}$$

$$CostEff_{MFR} = \frac{EffCost}{\sum_{i}^{i+35} \left[\left[\left(RCO2_{t-1} - RCO2_1 \right) + \left(CO2_{t-1} - CO2_t \right) \right] \times VMT_{D,CO2,i} \right] \times \frac{1}{(1 - Gap)}}$$

$$= \frac{TechCost - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i} \right)_{t-1} - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i} \right) \times \sum_{i=1}^{PP} \left[VMT_{D,FS,i} \right] \times \frac{1}{(1 - GAP}}{\sum_{i}^{i+35} \left[\left[\left(RCO2_{t-1} - RCO2_1 \right) + \left(CO2_{t-1} - CO2_t \right) \right] \times VMT_{D,CO2,i} \right] \times \frac{1}{(1 - Gap)}}$$

ATTACHMENT 3

MODEL REFERENCE GUIDE

Vehicle Greenhouse Gas (VGHG) Application

Quick Reference Guide

Model Version: .9

Introduction:
This document is to serve as a quick reference guide for using the Vehicle Greenhouse Gas application and the associated input spreadsheet files.

Input Spreadsheets:
There are four spreadsheets, in the current version of the application, that are required for a given scenario. Each spreadsheet consists of multiple worksheets as follows:

1. Scenario Spreadsheet (**Scenario.xls**)
   a. Scenarios – contains scenario run parameters and references to associated input files, suffixed by the scenario id number, e.g. Market-1.xls
   b. Economics– provides economic parameters such as discount rate and payback period
   c. Targets – contains cycle-specific, user-entered target values for cars and trucks
2. Market Spreadsheet (**Market-1.xls**)
   a. Market Data – provides sales and engineering information for each vehicle for each given scenario run
   b. MFR Sales – provides inputs corresponding to sales percentages by manufacturer used to generate generic model records
   c. Vehicle Type – provides lookup information associated to inputs and linkage between the market file spreadsheets for each vehicle type
3. Technology Spreadsheet (**Technology-1.xls**)
   a. Vehicle Type (1…X) Worksheet – contains technology cost, efficiency, and market cap assumptions and other related information specific to a vehicle type
4. Fuels Spreadsheet (**Fuels-1.xls**)
   a. Fuel – contains the forecasted fuel prices by year as well as fuel's chemical properties

Each spreadsheet also contains an Error Worksheet that provides the **Validate Data** button. If errors exist throughout the separate worksheets, the error messages will be presented after the data validation. Note that skipping the data validation can result in unexpected behavior in the application.

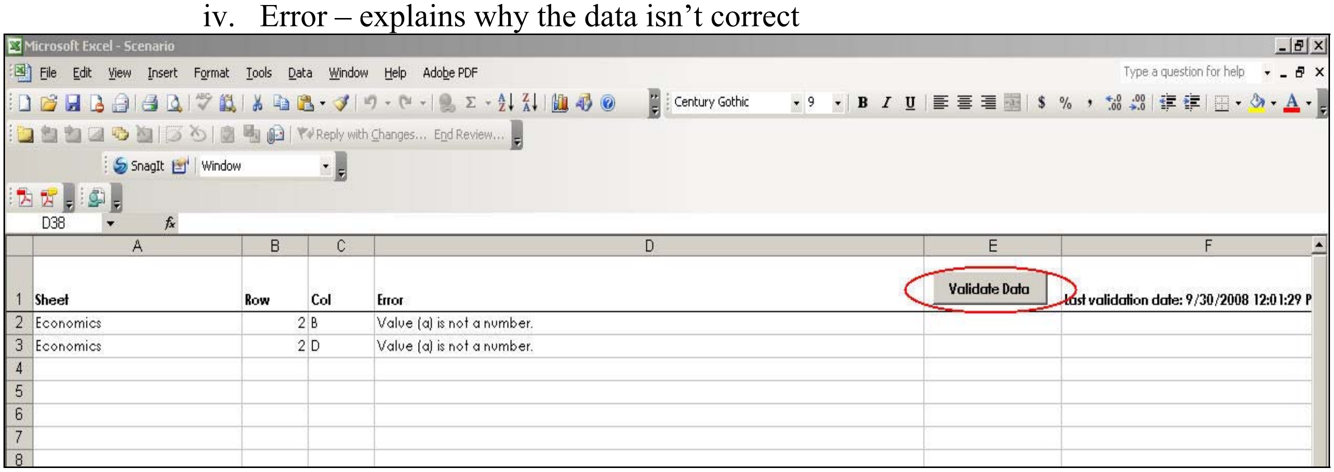
All spreadsheet column headers include special color coding to indicate if and how the associated column values are used.
Green background indicates, columns that contain lookup values, e.g. Vehicle Type column in the Market spreadsheet.
Yellow background indicates values that are auto-generated by the spreadsheet and/or read-only, e.g. ID column in the Scenario

spreadsheet.
Gray background indicates columns with values that are read in but not currently used, e.g. Horsepower in the Market spreadsheet.
Turquoise background indicates calculated values, e.g. Combine FE in the Market spreadsheet.

Instructions:

Updating the Spreadsheets:

1. Navigate to the folder containing the spreadsheets. (C:\Program Files\VGHG\Input)
2. Open input spreadsheet(s), starting with the Scenario spreadsheet and modify input parameters as needed. (Note not to add any data rows in the Scenario.xls)
3. Click on the Error tab.
4. To verify the accuracy of the new data, click on the **Validate Data** button.
    a. If no errors exist, the Error Worksheet will remain blank.
    b. If errors exist, the Error Worksheet will have a row populated per error. The column headers convey the following information:
        i. Sheet – worksheet the error will be found
        ii. Row – row number on the proceeding worksheet where error will be located
        iii. Col – column where error will be located
        iv. Error – explains why the data isn't correct



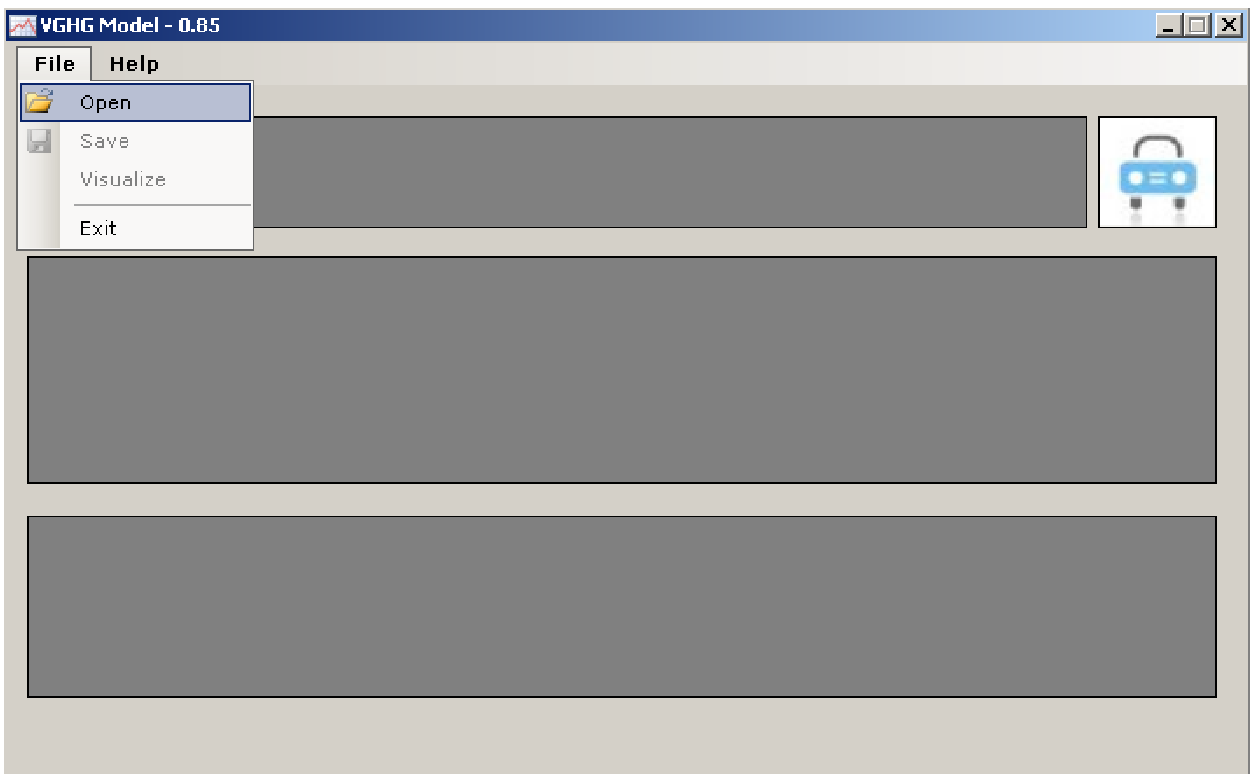
5. If no errors exist, save the spreadsheet.
6. If errors exist, the individual cells will be highlighted in red. Make the appropriate changes and then save the spreadsheet.
7. Follow similar process with the other 3 related spreadsheets until all run data has been entered and validated.

Common Error Examples

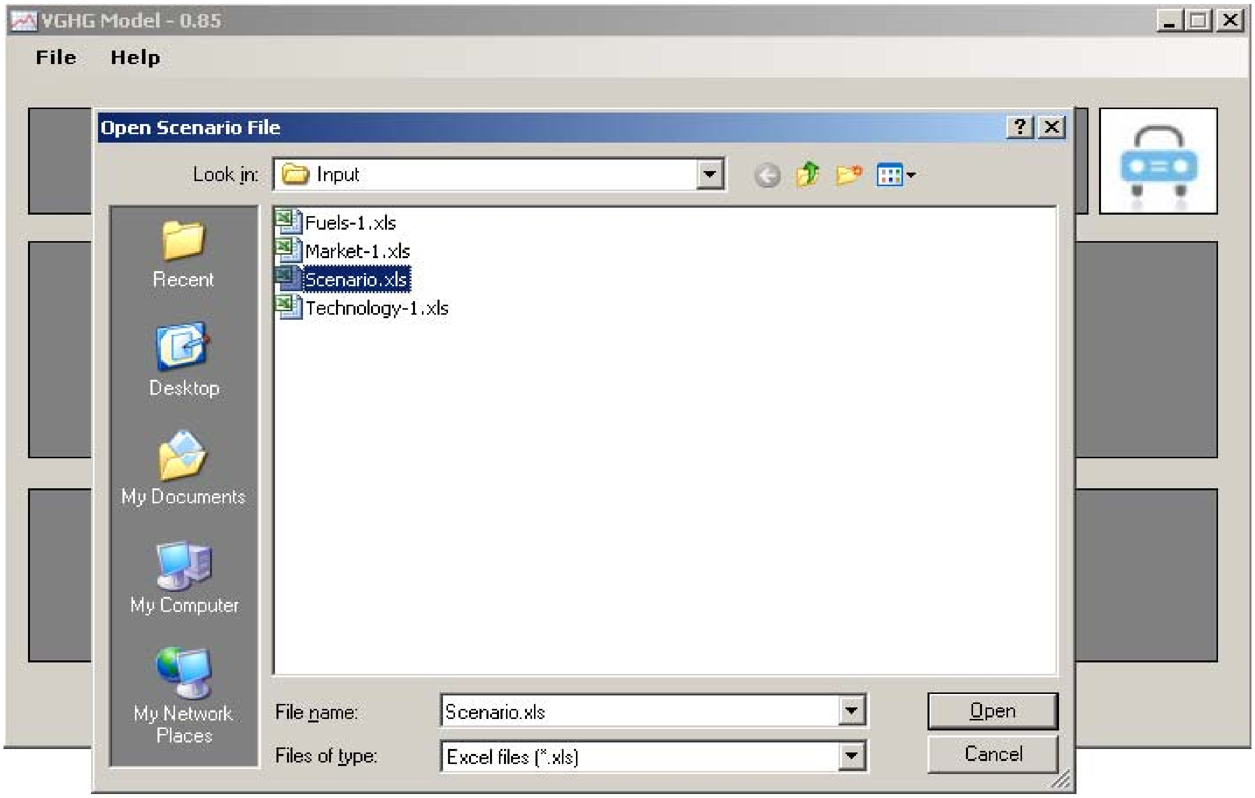
Issue	Fix
Blank Field – Value () is not a number.	Enter a number into the field
String Field – Value (1) is not a string.	Enter an alphabetic string into the cell
Number Field – Value (A) is not a number.	Enter a numeric value into the cell
Percentage Field – Value (1200) must be equal to or less than 1.	Enter a numeric value between 0 and 1 into the cell

Running the application:

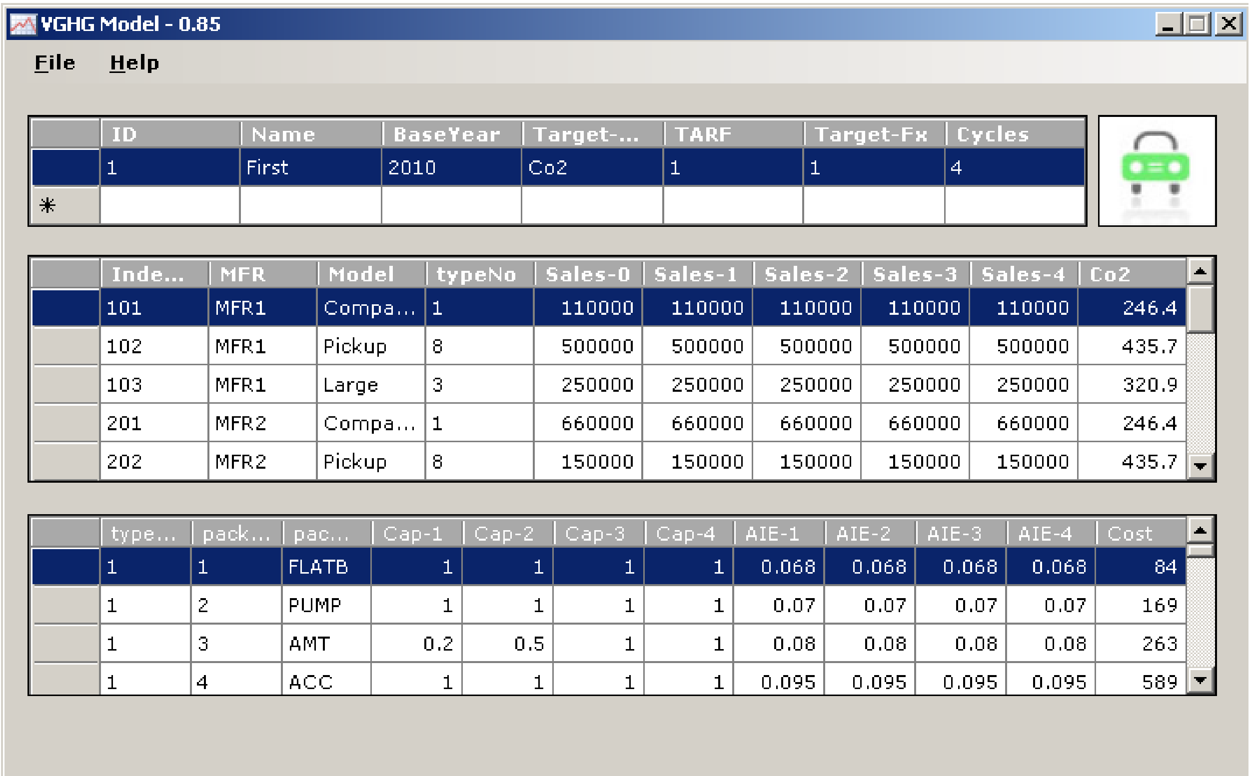
1. On the desktop, click on the VGHG icon to open the VGHG application. You will be presented with the VGHG Model user interface.



2. Click on the File drop-down and select the ‘Open’ option. You will be presented with the Open Scenario File pop-up box.



3. Select the Scenario.xls file and Click Open.   The tables will be populated with data from the four spreadsheets.
4. Verify that the correct data has been populated into the VGHG Model.

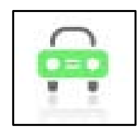


	ID	Name	BaseYear	Target-...	TARF	Target-Fx	Cycles
	1	First	2010	Co2	1	1	4
*							

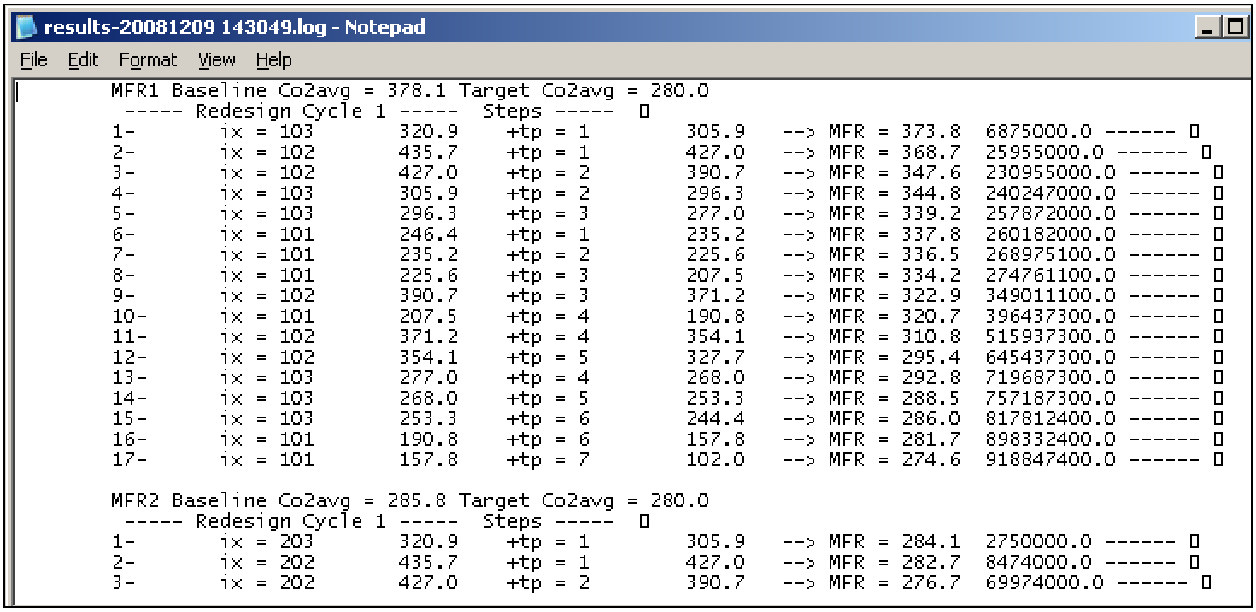
	Inde...	MFR	Model	typeNo	Sales-0	Sales-1	Sales-2	Sales-3	Sales-4	Co2
	101	MFR1	Compa...	1	110000	110000	110000	110000	110000	246.4
	102	MFR1	Pickup	8	500000	500000	500000	500000	500000	435.7
	103	MFR1	Large	3	250000	250000	250000	250000	250000	320.9
	201	MFR2	Compa...	1	660000	660000	660000	660000	660000	246.4
	202	MFR2	Pickup	8	150000	150000	150000	150000	150000	435.7

	type...	pack...	pac...	Cap-1	Cap-2	Cap-3	Cap-4	AIE-1	AIE-2	AIE-3	AIE-4	Cost
	1	1	FLATB	1	1	1	1	0.068	0.068	0.068	0.068	84
	1	2	PUMP	1	1	1	1	0.07	0.07	0.07	0.07	169
	1	3	AMT	0.2	0.5	1	1	0.08	0.08	0.08	0.08	263
	1	4	ACC	1	1	1	1	0.095	0.095	0.095	0.095	589

5. Click on the green car button.



6. The system will run the model and present the step wise results for each cycle and manufacturer in a text file at the end of the execution.

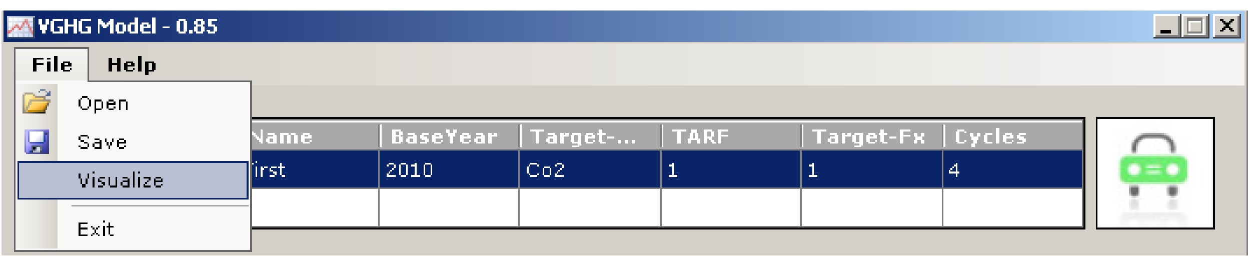



```
        MFR1 Baseline Co2avg = 378.1 Target Co2avg = 280.0
         ----- Redesign Cycle 1 -----  Steps -----  □
        1-       ix = 103       320.9    +tp = 1        305.9    --> MFR = 373.8   6875000.0 ------ □
        2-       ix = 102       435.7    +tp = 1        427.0    --> MFR = 368.7   25955000.0 ------ □
        3-       ix = 102       427.0    +tp = 2        390.7    --> MFR = 347.6   230955000.0 ------ □
        4-       ix = 103       305.9    +tp = 2        296.3    --> MFR = 344.8   240247000.0 ------ □
        5-       ix = 103       296.3    +tp = 3        277.0    --> MFR = 339.2   257872000.0 ------ □
        6-       ix = 101       246.4    +tp = 1        235.2    --> MFR = 337.8   260182000.0 ------ □
        7-       ix = 101       235.2    +tp = 2        225.6    --> MFR = 336.5   268975100.0 ------ □
        8-       ix = 101       225.6    +tp = 3        207.5    --> MFR = 334.2   274761100.0 ------ □
        9-       ix = 102       390.7    +tp = 3        371.2    --> MFR = 322.9   349011100.0 ------ □
        10-      ix = 101       207.5    +tp = 4        190.8    --> MFR = 320.7   396437300.0 ------ □
        11-      ix = 102       371.2    +tp = 4        354.1    --> MFR = 310.8   515937300.0 ------ □
        12-      ix = 102       354.1    +tp = 5        327.7    --> MFR = 295.4   645437300.0 ------ □
        13-      ix = 103       277.0    +tp = 4        268.0    --> MFR = 292.8   719687300.0 ------ □
        14-      ix = 103       268.0    +tp = 5        253.3    --> MFR = 288.5   757187300.0 ------ □
        15-      ix = 103       253.3    +tp = 6        244.4    --> MFR = 286.0   817812400.0 ------ □
        16-      ix = 101       190.8    +tp = 6        157.8    --> MFR = 281.7   898332400.0 ------ □
        17-      ix = 101       157.8    +tp = 7        102.0    --> MFR = 274.6   918847400.0 ------ □

        MFR2 Baseline Co2avg = 285.8 Target Co2avg = 280.0
         ----- Redesign Cycle 1 -----  Steps -----  □
        1-       ix = 203       320.9    +tp = 1        305.9    --> MFR = 284.1   2750000.0 ------ □
        2-       ix = 202       435.7    +tp = 1        427.0    --> MFR = 282.7   8474000.0 ------ □
        3-       ix = 202       427.0    +tp = 2        390.7    --> MFR = 276.7   69974000.0 ------ □
```

At the end of the run you have the option to save the results as an XML file to load into the Benefits workbook or use it for other types of post processing analysis. To save the result data to an XML file, select File|Save from the menu.

You may also run this XML file thru a built in transformation package to "Visualize" the results.



Below is a partial display of the html page produced using the "Visualize" option:

VGHG Results

- Total TP Additions: 55
- Cumulative Costs: $1,609,640,000

Name:	First
BaseYear:	2010
TargetType:	Co2
TarfOption:	1
TargetFunType:	1
Cycles:	4

Tech Pack Selections

Manufacturer	Model	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Ford	Explorer	• 1 • 2 • 3	• 1 • 2 • 3	• 1 • 2 • 3	• 1 • 2 • 3 • 4
Ford	F 150	• 1 • 2	• 1 • 2	• 1 • 2 • 3	• 1 • 2 • 3 • 4 • 5 • 6
Ford	Focus	• 1	• 1 • 2 • 3	• 1 • 2 • 3 • 4	• 1 • 2 • 3 • 4 • 5
Ford	Fusion	• 1 • 2 • 3	• 1 • 2 • 3	• 1 • 2 • 3 • 4 • 5	• 1 • 2 • 3 • 4 • 5
Final Avg CO2	**Ford**	253.6	235.6	217.4	199.6

Details

Manufacturer	Model	Cycle 1	Cycle 2	Cycle 3	Cycle 4

Ford	Focus	• Step 9
		  • TP = 1
		  • 246.4 -> 235.2
		  • Cuml Cost = $93,845,600
			• Step 9
			  • TP = 1
			  • 246.4 -> 235.2
			  • Cuml Cost = $116,675,600
			• Step 10
				• Step 9
				  • TP = 1
				  • 246.4 -> 235.2
				  • Cuml Cost = $150,025,600
				• Step 10
					• Step 9
					  • TP = 1
					  • 246.4 -> 235.2
					  • Cuml Cost = $150,025,600
					• Step 10

ATTACHMENT 4

BENEFITS CALCULATIONS INSTRUCTIONS

Benefit Calculation Spreadsheet
Vehicle Green House Gas Model

The Benefit Calculation spreadsheet is an analysis tool for determining the total cost savings from CO_2 reductions forecast by the Vehicle GHG model. The January 23, 2009 version of the spreadsheet includes a number of modifications to facilitate both expandability and error checking

The original spreadsheet has been reorganized to facilitate a smooth connection to the Vehicle GHG core model. Major changes include:

- The original input worksheet has been divided into four separate sheets:
  - Load, which serves as the point of entry for output from the model. The name of the most recent loaded XML file is displayed on this page as well as some additional information.
  - Model Results, which contains the manufacturer/model/redesign results from the Vehicle GHG model. This sheet also includes a number of aggregations to the Car/Truck level by redesign cycle.
  - Exclusive Inputs, which include inputs required only by the Benefits Calculation spreadsheet. These are primarily physical constants and emissions damage costs.
  - Shared Inputs, which are required by both the Benefits Calculation spreadsheet and the Vehicle GHG model (e.g. the discount rate, payback period and fuel price forecast.) These values are also read from the Vehicle GHG output to insure that the Benefits Calculations use the same values used by the model.
- VBA code has been added to handle data import from the model.
- The Benefits2 (Sales) tab has been reoriented so that the sales forecast goes down rather than across. This is for easier viewing of the data.
- The VMT_Lookup sheet includes a table of VMT by vehicle age with separate columns that reflect different first year starting points – these are calculated from the rebound effect.
- The VMT_Rebound_Effect table includes all of the Model Year / Calendar year data that was originally included in the triangular tables.
- The AnnualTotals table summarizes information from the VMT_Rebound_Effect sheet into Calendar year totals.
- The remaining pages in the Benefit Calculation spreadsheet have been updated so that all references are to the new pages.
- Note that the cell background color scheme (see the legend on the Load sheet), is used on all pages.
- Several pages were no longer required as their functionality has been moved to the new sheets. These have been removed from the spreadsheet to eliminate confusion (and to greatly reduce the size of the spreadsheet)

Loading Model Results:

The system transfers data from the Vehicle GHG model to the Benefits Calculation spreadsheet via an XML file that is exported by the model after all redesign cycles are complete. The XML file contains and organizes all of the spreadsheet input data and the model output data. This approach of using a separate XML output file allows for flexible integration into other future post-processing spreadsheets since all of the important data is organized into a single file. Results from a Vehicle GHG scenario run may be loaded automatically into the appropriate cells in the Benefit Calculation spreadsheet via the **Load** button that appears on the "Load" tab. Data read from the Vehicle GHG scenario includes:

- CO2 emission and cost forecasts for each make and model in each redesign cycle.
- Vehicle sales data for each make and model in each redesign cycle.
- Shared Inputs

The spreadsheet contains the following sheets:

Sheet Name	Purpose	Comments
Load	Specify scenario and read in the XML outputs from Vehicle GHG.	Loads data for up to four manufacturers and a maximum of four redesign cycles. Note that the XML file is usually located in the .\output subdirectory of the VGHG installation directory.
MODEL RESULTS	Summarizes model outputs in a flat table. Also includes Redesign cycle totals and averages for Cars and Trucks	If data is read in for less than eight cycles, values from the last cycle read in will be copied forward to fill in a full eight cycles.
EXCLUSIVE INPUTS	Data values required by the Benefits Calculation spreadsheet, but NOT by the core Vehicle GHG mode	
SHARED INPUTS	Data values require by both the Vehicle GHG model AND the Benefits Calculation spreadsheet.	
BENEFITS2 (SALES)	Interpolates annual Car and Truck sales based on the input data for sales in the redesign cycles.	Sales forecast now extends through all eight redesign cycles (2050)
VMT_Lookup	Tables of VMT by vehicle age with increasing values calculated from the rebound effect.	
VMT_Rebound_Effect	All Model Year / Calendar year calculations for impacts due to the rebound effect. This includes both costs and benefits.	
AnnualTotals	Calendar year totals for the model year / calendar year data on the VMT_Rebound_Effect pag.	Note that the Baseline and earlier CO_2 values for Cars and Trucks are included as the last two columns on this tab.
EXTERNALVMTCOSTS ($)	Calculate negative impact of rebound VMT due to Congestion, Accidents and Noise	
DOWNSTREAMCOSTS ($)	Summarizes downstream costs calculated on the above six worksheets. Applies a discount rate to determine the net present value of the future cost stream.	

Sheet Name	Purpose	Comments
FUELCOSTS ($)	Calculates cost savings due to reduced fuel consumption.	
EXTERNALCRUDECOSTS ($)	Calculates cost savings due to reduced need for crude oil.	
UPSTREAMCOSTS ($)	Calculates the upstream savings due to reduced emissions of CO_2, CO, VO_X, NO_X, PM and SO_2 due to reduced need for gasoline production from crude oil.	
ALL NON-TECH COSTS	Summary of all Non-Technology costs and benefits for a given Vehicle GHG scenario.	
TECH COSTS	Summary of Technology costs from the model.	
ALL COSTS	Summary of Technology and Non-Technology costs.	

APPENDIX C

JOHN GERMAN'S REVIEW DOCUMENT

The charge to reviewers was, "EPA staff are 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." The emphasis of my review is on the inputs to the model and the model concepts and methodologies. I did not devote much attention to the outputs and whether or not the model executes the algorithms correctly, as the model will certainly evolve and improve over time. Thus, assessing outputs and proper execution of algorithms will be a living, constantly changing challenge, as the model itself changes. My time and expertise is better spent focusing on inputs and model structure. (Not to mention that I just ran out of time.)

Concepts and Methodologies Upon Which the Model Relies:

(A) Model structure

The model is an accounting model. This is neither good nor bad. The advantage is that it avoids overmodeling and embedding errors in the model itself. The disadvantage is that the factors affecting the results are all inputs to the model. This requires a great deal more sophistication and work by anyone using the model to prepare the inputs properly. It will also make it more difficult for anyone outside EPA to use the model, unless EPA is willing to provide the detailed inputs to other users.

With this type of model, it is essential that EPA release the data in the Technology and Economics input files and discuss them in the Notice of Proposed Rulemaking, as the real analyses and modeling are in these input files. But as long as this is done, the overall model construction is fine.

(B) Redesign cycles

I completely agree with EPA's logic in creating a model based upon vehicle redesign cycles. As EPA states, adding technologies incrementally to each vehicle model by model year does not add value to the model results. Using redesign cycles also allows for simplification of the fleet. It is impossible to predict the direction of vehicle redesigns for each manufacturer. It is just as accurate to assume, for example, that future mid-size cars from each manufacturer will be identical; as it is to assume that current differences in mid-size cars from one manufacturer to the next will be continued into the future. As a recent example, Honda left their compact crossover, the CR-V, virtually unchanged in size during the latest redesign. However, Toyota chose to lengthen their compact crossover, the RAV4, by 14" during its latest redesign. It is pointless to try to predict differences in vehicles from different manufacturers in the future and it is pointless to try to predict the exact year when redesigns will occur. This is a welcome simplification.

Another advantage of using redesign cycles is that GHG standards for interim model years can only be set, reasonably, as a straight line (or a constant % decrease) between the baseline year and the end of the redesign cycle. This is appropriate. Constant yearly % reductions provide a consistent signal to manufacturers for investment decisions.

However, there is one potential problem with using redesign cycles. It masks the investment needed to bring new technology to the market. The auto industry is extremely capital intensive. Initial investment in a new technology is expensive, both for tooling and the resources necessary to assess (and fix) system-level effects and effects on reliability, durability, safety, and manufacturing. Redesign cycles tend to assess only the costs for high-volume production and skip over the high initial costs. Care must be taken to properly assess costs in the inputs.

(C) Leadtime

The model handles leadtime issues far too simplistically. This was also a problem with the Volpe model. Leadtime is one of the most important issues in setting standards and one of the most difficult issues to assess properly. Thus, it is disappointing to see both NHTSA and EPA provide so little attention to the issue.

The only leadtime constraints in the draft model are industry-wide caps on the maximum technology penetration by redesign cycle and vehicle type. There are several problems with this approach:

- The largest problem is that it is inappropriate to treat all manufacturers the same. A manufacturer that has already invested in a particular technology in the baseline year will be capable of higher penetration rates than a manufacturer that has never used the technology before – and also of producing the technology at lower cost. An obvious example is hybrid vehicles. Over 10% of Toyota's vehicles already have hybrid systems on them. After introduction of the CR-Z next year, Honda should also have more than 10% hybrids. Due to their experience and head start with hybrids, both manufacturers will be capable of much higher penetration rates than most other manufacturers. They are also further along the learning curve, so their costs will be lower. Similar situations exist with most technologies.
- Another problem is that costs will vary from manufacturer to manufacturer. As noted in my comments on redesign cycles, above, there are large upfront costs when a manufacturer introduces a new technology. For example, Toyota has already amortized large R&D and system-level costs for hybrid vehicles. They will be able to produce hybrids cheaper than manufacturers that are just starting to offer hybrids. The point is that the "Initial Incremental Cost" in the Technology Input File should not be applied to all manufacturers at the same time, but rather to each manufacturer at the time they first introduce a new technology.
- The third problem is that there is no such thing as a hard cap on technology penetration rates. There is a tradeoff that exists between cost and leadtime. Technology introduction can be accelerated by increasing investment – and cost and risk.

Long-Term Recommendation – The best way to handle leadtime constraints and technology penetration is to assess capital investments by manufacturer. This would require adding a new section on capital expenditures. In addition to assessing the cost of each technology, the capital expenditure would also be assessed. Ideally, there would be two components to the capital expenditure assessment for each technology, one for R&D expenditures for the first implementation of the technology and one for the capital investment needed to add the technology to additional models. However, the second is more important. Each manufacturer would be assigned a total capital expenditure budget for the redesign cycle and technologies could only be added up to the point where the sum of the technology capital expenditures did not exceed the manufacturer cap. Alternatively, some increase in technology penetration over the cap could be allowed, but only if coupled with increasing technology costs. This would appropriately handle leadtime constraints and technology penetration rates.

Short-Term Recommendation – The long-term recommendation would require a lot of new work and is clearly not feasible in the timeframe needed for EPA's rulemaking. As a short-term fix, instead of using industry-wide caps on maximum penetration for each technology, EPA should:

(a) Set caps on the maximum increase permitted per year. This would be applied to each manufacturers' individual technology penetration; and

(b) Establish the model year for initial introduction. For technology that has not been introduced to the market yet, this year could be the same for all manufacturers. For a technology that is already being used by a manufacturer, the baseline year would be used for that manufacturer. However, if a manufacturer were not using a technology yet, even if another manufacturer is using it, a year of introduction would need to be set for that manufacturer.

(c) Some technologies would still need caps on maximum penetration. However, this should reflect market restrictions, not leadtime constraints. This would incorporate consumer values for particular technologies that go beyond just efficiency and performance. For example, even though manual transmissions are more efficient than automatics, most consumers will not give up the convenience of an automatic. PHEVs do not have much benefit for people driving a lot of highway miles each day. Diesels are desired for trailer towing and have advantages on highway fuel economy, while hybrids have advantages in stop-and-go driving. These types of market considerations can be handled by establishing maximum penetration caps, but they should be handled separately from how leadtime is handled by manufacturer.

Note that the yearly cap and introduction date violates the design cycle principal, but it is important to create the proper cap for each manufacturer and technology combination. Instead of using a model year for (b), above, the user could specify how many years into the design cycle a technology could be introduced.

(D) Technology Assessment

Requiring the user to input technology in rank order of cost-effectiveness is an interesting attempt to handle the synergy issue. Unfortunately, it fails to work in other ways:

- It only works if the learning rate is the same for all technologies and if no technology changes effectiveness over time. If one technology has a steeper learning curve than another, or if a technology increases benefits in the future, then the cost-effective order will change over time. For example, high-tech diesels are a relatively mature technology, as over 5 million per year have been sold in Europe for several years. Their future cost reduction potential is much less than that of hybrid vehicles, whose sales are at least an order of magnitude lower and which are still at early stages of development. Also, the high power Li-ion batteries just starting to penetrate the market will allow much smaller battery packs for conventional hybrids, with large cost reductions. In addition, analyses by MIT (2007) suggest that hybrid benefits will increase in the future as manufacturers figure out how to use the hybrid system to minimize operation at less efficient engine speed/load points.
- The synergies will differ depending on the specific technologies into which an individual

manufacturer has already invested. For example, consider one manufacturer that has invested in MPI turbos and a second that has invested in DI naturally aspirated engines. If both manufacturers move to DI turbo engines, the first manufacturer will gain the benefits of DI adjusted for the DI/turbo synergies, while the 2nd manufacturer will gain the benefits of turbocharging adjusted for the same DI/turbo synergies. Thus, the synergy impact of DI/turbo must be assessed independently of each technology. Even if the model ignores the leadtime constraints imposed by baseline technology investment and assumes every manufacturer will adopt the exact same technology packages for a given vehicle type (not a good idea, as discussed, above), a problem still exists in backing out "any advanced technology that might have been present in the baseline" (page 12, line 3-4). In order to back out the baseline technology for different vehicles and manufacturers, the technology input file must contain independent assessments of MPI turbo, DI naturally aspirated, and DI turbo. The DI turbo line includes the synergies, but the other two lines do not. How does the model add them back in? If the turbo lines and DI lines occur before the DI turbo line, then the technologies will be added together first without consideration of the synergy effect.

- It does not allow for different markets for different technologies. For example, diesel engines have additional value for (a) customers who tow and (b) customers in rural areas. Towing is valued only by a small part of the market, but it is an important feature for that market. Customers in rural areas do a lot of highway driving and value the high efficiency of the diesel on the highway, while hybrids excel in urban areas. Thus, the markets for diesels and hybrids will be self-selected to some extent by their relative city and highway mpg, not the combined mpg used to select all technology.

In order to work properly, the model must be able to handle multiple pathways. For example, the model cannot allow turbo and DI benefits to be added sequentially, but must force each to go to a DI turbo input. A similar situation exists with the various variable valve timing systems and VCM. All offer primarily pumping loss reductions and all options must be present in the input file in order to back out technologies in the baseline. All these options cannot be added back by the model one after the other – the model must also be able to handle these multiple pathways. Another example is transmissions, where the input file must list 5-, 6-, 7-, and 8-speed automatics, as well as DCTs and CVTs (even ignoring manual transmissions). I could go on. The point is that I do not see how the model can avoid handling multiple technology pathways and depend only on the input order to handle synergies.

The model must also be able to handle technologies with different rates of change in benefits and costs in the future. This also requires that the model process the lines independently and not rely on the input order.

The market considerations could perhaps be handled with maximum penetration caps. For example, it could be considered that diesel engines will not compete well with hybrids in urban areas, so that the maximum penetration of diesels would be equal to their sale in rural areas plus trucks designed to tow, with the reverse true for hybrids. Of course, this will differ by manufacturer, which is a problem if universal caps, instead of manufacturer-specific caps, are maintained.

(E) Maximizing Net Social Value

The model only outputs total costs and benefits. It presents these with great amounts of detailed information. But it is impossible to tell if the scenario has maximized net social value.

To put it another way, the model is only capable of counting up the benefits and costs of complying with pre-determined GHG standards. It is not able to do the reverse, which is to input the desired benefit and have the model determine the resulting GHG standard.

This is not a trivial issue. The 2007 EISA specifically mandates "maximum feasible" CAFÉ standards after 2020. NHTSA has long interpreted existing statutory authority to also require maximum feasible standards and established long ago that "maximum feasible" is determined by the point at which the costs of adding the next technology exceed the benefits. Even without a mandate, any credible analysis must be able to compare the costs and benefits of the chosen GHG standard to the maximum net social value.

Given the existing complexity of the model, it is not unreasonable for the model to also determine the GHG standard that maximizes net social value. The Volpe model calculates this point even with a much more complex model. EPA's model will lose considerable credibility if it is not capable of calculating the maximum net social value point.

Appropriateness and Completeness of the Contents of the Sample Input Files:

(F) Market Input File

The market input file appears to be appropriate and complete – perhaps too complete in one way. The file contains separate inputs for reference case technology benefits and costs. The percentages in these columns should simply reflect the existing market penetration of each technology package. They should be identical for both costs and benefits. Is there a reason why these would be different? If so, the Model Description should explain this. If not, the duplicate columns can be removed.

Minor Suggestions:

- If the model wants to "back out" existing technologies, you will need a lot more than 20 columns to do this. You'll need 10 columns just to handle transmissions and another 10 just to handle different valve timing systems. Not to mention differing levels of high strength steel and aluminum use.
- The Model Description should state that vehicle types are a user input defined in the "Vehicle Type" tab of the Market Input File (I looked around for a while before I found this.)
- If you maintain separate columns for reference case technology costs and benefits, it would help the user to add a row above the existing descriptions and define columns AD-AW as "reference case benefits" and columns AX-BQ as "reference case costs".

(G) Technology Input File

As discussed above, the technology input files need to be substantially modified in conjunction with changing the model to handle multiple technology paths.

In addition, also as discussed above, the "Cap Cycle" numbers need to be replaced with generic caps on the maximum increase permitted per year and manufacturer-specific model years for initial introduction. The annual technology penetration increase cap would be applied to each manufacturers' individual baseline technology penetration, from the Market Input File, or starting with the manufacturer-specific initial model year for technology packages that have not been used yet by individual manufacturers.

The Average Incremental Effectiveness fields are fine, although, as noted above, if these change for future redesign cycles, the cost-effective order of the technology packages can also change.

I could not find any explanation of how the Initial Incremental Cost, α, Decay, seedV, kD, and Cycle Learning Available fields are used in the model. Even the detailed algorithms on pages 9-16 of the Model Description contain no reference to how technology costs are adjusted for the TARF calculations. Thus, I was not able to assess the appropriateness of these fields. However, in general, the cost reduction curve is not likely to be the same for all technologies. Some flexibility may be needed here.

The Technology Input File does not address weight impacts associated with different technologies. For example, both diesel engines and hybrids add considerable weight to the vehicle, which negatively impacts both performance and efficiency. It is possible to handle this off-board in the efficiency benefit estimation. However, if so the Model Description should explicitly state that weight impacts are expected to be assessed by the user and included in the technology inputs.

(H) Scenario Input File

The compliance options – universal standard, linear attribute, or logistic attribute – are fine.

However, there are columns in the Scenario input file that are not described in the Model Description on page 6:

- TARF Option (column E) – Is this the "two TARF equations from which the user can choose", described on page 13? If so, should state this on page 6.
    - Why is the "Effective Cost" TARF equation limited to fuel savings over the payback period? Why aren't the discounted lifetime fuel savings considered? Is this done to try to mimic what technologies will be most acceptable to the customer? If so, this should be explained in the Model Description. I'm also not sure this is appropriate. Most technologies will be invisible to the customer. In addition, the primary point of CAFÉ and GHG standards is to fill in the gap between the consumers' value of fuel savings and the value to society. So, the standards should be targeted towards society's values, not the customers.
    - The equation for "Cost Effectiveness – Manufacturer" equation does not make sense.

Unless a technology includes a fuel change, this equation will produce virtually identical results for all technologies. The CO_2 summed in the denominator is directly proportional to fuel consumed summed in the numerator. The ratio should be virtually the same for all technologies, unless there is a fuel change. What is this equation trying to do?

  - Why is the fuel savings only summed over the payback period, while the CO_2 savings are summed over the useful life? Why are they not the same?

- Target Function Type (column F) – I could not find a description of this field anywhere in the Model Description.
- Fleet type (column G) – The description in Rykowski's email response to Rubin should be added to the Model Description.
- Trading limit (column I) – The description in Rykowski's email response to Rubin should be added to the Model Description.

Economic parameters – The "CAFÉ fine" and "CO_2 value increase rate" are fine. However, the other parameters may need modification:

- Discount rate – There is some thought that the CO_2 discount rate should be different from the economic discount rate. I am not sure I agree with these arguments, but you may want to include flexibility to have a different discount rate for CO_2 in the model.
- Payback period – As discussed, above, I am not sure this is needed. Any use of payback period should be explained and justified in the Model Description.
- CO_2 fine – While the CAFE fine is used appropriately in the model, there is no consideration of a manufacturer paying CO_2 fines instead of complying with CO_2 standards. Of course, this is dependent on the compliance strategy adopted by EPA for its CO_2 standards. But the model should have the flexibility to model CO_2 fines; similar to how it handles CAFÉ fines.
- Gap – It is appropriate to adjust the test values for differences in real-world fuel consumption. However, the gap is not linear. As EPA demonstrated in their fuel economy label rulemaking, the gap increases as fuel consumption decreases. While the fuel economy label adjustments overstate the actual gap, the curves for city and highway fuel economy labels from the generic equations are illustrative. The model should add the ability for the user to input a nonlinear gap function.
- I do not understand the value of "threshold cost" or how it is used. Lines 8-10 of page 8 state, "threshold technology cost (the cost at which manufacturers add technology to only enough vehicles to meet the standard as opposed to adding technology to all of a model line)". The detailed calculations later in the Model Description do not discuss how this is done. From a practical point of view, how does the model know whether or not the technology is needed to meet the standard when the technologies are feed into the model one at a time? More importantly, manufacturers have limited resources and the standards will drive technology development well beyond what a manufacturer would have done without them. Thus, why would a manufacturer add any technology to more vehicles than are required to meet the standard? Unless these concerns can be addressed in the Model Description, the "threshold cost" should be eliminated.
- Rebound effect – Line 38 on page 17 states that the rebound effect is an input in the "Economics" worksheet. However, it is not listed in the worksheet. In any case, the rebound effect is not handled appropriately in the model. The rebound effect is a sensitivity factor.

But it is determined from a regression. Which means that the change in VMT is NOT a linear function of the change in fleet fuel consumption. Thus, the equation on lines 41-43 of page 17 is wrong. The actual relationship is logarithmic or exponential or something like that (I don't remember exactly what). The correct equation should be built into the model.

  - The rebound effect is also impacted by the price of fuel and household income. This should be added to the model (see medium- to long-term recommendations, below).

Minor suggestions:

- It appears that the "Cars A", "Cars B", "Cars C", and "Cars D" columns in the Target tab are intended to describe the footprint-based logistic curve. Does this mean that "Cars C" and Cars D" are also the Xmax and Xmin under the linear attribute option? If so, both descriptions should be in the column headings. Also, while the Model Description (page 6-7) includes a good explanation of the how the linear target and logistic curve work, it should also specifically state where the A, B, C, D, and X coefficients can be found in the spreadsheet.
- The economic parameters are discussed as part of the Scenario input file on page 8. Lines 12-13 also state that an example of the Scenario input file is in Appendix 3. However, Appendix 3 only includes the "Scenarios" tab and the "Target" tab. The "Economics" tab should also be added to Appendix 3.

(I) Fuels Input File

The fuels file works fine for conventional gasoline and diesel. The Model Description does not address biofuels, but if needed the Fuel Input and the Upstream Emissions worksheets should be able to handle them.

Electricity is a special problem. A minor issue is that the Energy Density (column B), Mass Density (column C), and Carbon density (column D) are different than for liquid fuels. Liquid fuels are generally expressed in units per gallon. This doesn't work for electricity. The units for electricity in the Fuels Input sheet need to be defined. Also, I'm not sure what Mass Density would be for electricity – kg/kWh? And isn't carbon density meaningless, as the carbon is all upstream?

More importantly, the energy density and mass density for electricity are not fixed, but are dependent on battery construction. High-power Li-ion batteries for conventional hybrids may only have about 15 Wh/kg energy density, while high-energy batteries for PHEVs and EVs may have over 100 Wh/kg. In addition, start/stop systems and belt-alternator/starter systems may use lead-acid batteries and some conventional hybrids may continue to use NiMH batteries through the 2013-2015 timeframe. All will have different energy densities.

Minor suggestions:

- The Model Description, line 6 page 6, says, "There is a small subset of fuel information not included in this file". This is not accurate. Appendix 5 contains upstream emissions, which is an extremely important factor for fuels. This connection should be discussed in the Model Description.
- The appendices should be ordered to match the order they are discussed in the Model

Description (i.e. the fuels Appendix should be before the Scenario appendix).

(J) Reference Data in Appendix 5

Downstream Criteria Pollutant Emissions:
The fields and the regressions as a function of age are appropriate. However, there is not enough flexibility to handle differences in fuel, future emission standards, and future fuel sulfur control:

- The model should be able to handle future reductions in emission control standards. This means that the model should allow the user to specify effective years for future emission standards and enter new regression coefficients.
- SO2 emissions are almost entirely a function of the sulfur level in the fuel. Thus, the model should also handle changes in fuel sulfur level. The model should allow the user to specify effective years for future sulfur reduction and the fuel sulfur level for both current and future fuels. If desired, the user would not have to enter regression coefficients for SO2, as there is a fixed relationship between fuel sulfur, fuel consumption, and SO2 emissions (much like CO2 to fuel consumption) that could be hard-coded in the model if the user specifies fuel sulfur levels.
- The regression coefficients will be different for gasoline, diesel, and electric vehicles. Average coefficients can be used for the current fleet, but these will not be appropriate if there is a substantial change in the future mix of diesels, PHEVs, or EVs. The model needs to allow input of different coefficients for diesel and gasoline – and possibly biofuels. Downstream emissions of electric operation should be zero and do not have to be input.
- It appears that the model does NOT calculate downstream pollutant emissions as part of the normal model accounting, only the additional emissions caused by the VMT rebound effect. This is not appropriate. If there is a switch to diesels or EVs, the downstream pollutant impact needs to be assessed by the model.

Upstream Emissions:

- The upstream emission inputs are fine for gasoline and diesel, although addition rows will likely be needed to handle biofuels and unconventional oils.
- It is not clear if the efficiency of battery recharging is included in electricity upstream emissions. The model likely calculates only the mmBtu actually used by PHEVs and EVs during use. However, the mmBtu draw from the utility will be larger due to losses in the battery charger and in the battery chemical process. To ensure that the user handles this properly, it would be best to add an input somewhere for charging efficiency. Otherwise, the Model Description should explicitly state that the upstream grams/mmBtu for electricity must be incremented to include the losses in the charger and battery.
- Upstream emissions, both carbon and pollutant, for electricity will vary by region. While it is the responsibility of the user to input proper factors, there is a potential issue with stratification of PHEV and EV sales across the nation. Customers in urban areas are most likely to buy PHEVs and EVs will likely be limited primarily to a few, dense urban cores. It might be useful to have the Model Description briefly discuss the need for the user to input upstream values for electricity that are consistent with utility emissions in the urban areas most likely to purchase PHEVs and EVs.

Vehicle Age Data and historical data on average CO_2 emissions and new vehicle sales:
These fields and inputs are fine.

(K) Other Reference Data

Externalities related to crude oil use:
The externalities in the Externalities worksheet of the Benefits Calculation are only listed for imported oil. This is appropriate for military costs for protecting oil supplies, but it is not for the economic impact of periodic price shocks (and possibly for monopsony effects as well). Oil is a global commodity. Any reduction in oil use, either domestic or imported, will help reduce the economic impact of periodic price shocks.

Rebound effects:
The discussion of the rebound effects on lines 10-19 of page 3 and on pages 20-21 both imply that rebound effects are NOT considered in assessing the societal benefits from reduced crude oil use and GHG emission reductions. However, I would assume that these benefits are based upon total fuel consumption, which includes the additional VMT from the rebound effect. If my assumption is not accurate, then the social benefits associated with reduced crude oil use and the value of GHG emission reductions must be revised to include the rebound effect. If the benefits do include the additional VMT from the rebound effect, this should be clarified in the discussion on both page 3 and page 20.

Recommendations for Improved Model Functionality – beyond "future work":

(L) Recommendations for Short-Term Functionality

The functionality of the model is good. My only recommendations are those already described above, for improved handling of leadtime (section C), ability to handle multi-path technology inputs, (section D), and ability to calculate "maximum net social benefits" (section E).

(M) Important Medium-Term and Long-Term Recommendations

1) By far the most important improvement is to use budgets for capital expenditures to assess leadtime. The need for this and suggestions on how to implement it were discussed in section (C), above.

2) The rebound effect is impacted by both the price of fuel and household income. These should be added to the model. The work has already been done by Small and vanDender. Their equations should be added to the model, along with the necessary user input fields for future household income. An option to skip the fuel and income effects can be maintained, but it is important that the model be capable of properly calculating rebound effects.

- The time value of congestion and vehicle refueling are also related to household income. While this is of lesser importance than the rebound effect, it should be relatively easy to add household income effects to the value of congestion and vehicle refueling in conjunction with adding household income to the VMT rebound effect.

(N) Less Important Long-Term Suggestions

3) Inclusion of the city and highway fuel economy/CO_2 values may help with assessing market penetration caps, although this can be done externally. Also, separate city and highway values could help calculate an appropriate in-use fuel economy/CO_2 "gap" for different technologies with different city/highway fuel economy ratios. Separate city and highway numbers might also be useful for other purposes. EPA should consider adding these to the model.

4) Value of time required to refuel vehicles:
The model handles this appropriately for liquid-fuel vehicles. However, PHEVs and EVs will add refueling time, both because of the need to plug in and, in the case of EVs, the shorter range. This should be added to the model. Ideally, it should also be added to the TARF assessment.

APPENDIX D

PAUL LEIBY'S REVIEW DOCUMENT

May 29, 2009
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Review Comments on
EPA's GHG Model and the documentation, "*Description and Methodologies of the EPA Vehicle Greenhouse Gas Emission Cost and Compliance Model*"
(Based on Drafts received May 1, 2009)

Thank you for the opportunity to review this model and its documentation. This is an important project, and the EPA team has made great progress in developing a coherent, informative, and very usable system. I understand that this is a work in progress and, regrettably, many comments can only refer to its current (May 1, 2009) state. Also most of the comments are in the form of what might be changed or improved, with the hope that these might be most useful. I would like to say at the outset that everything achieved so far is well worthwhile, and some features are quite marvelous. Please also interpret statements below of the form "the model does/does not" as meaning "as far as I could discern so far, it seems like the model does/does not." Statements like "the model/documentation should" really mean "Perhaps it would be helpful if the model/documentation were adjusted to…." In sum, this work is to be applauded and I look forward to its next iteration. Comments are offered in order of the questions posed, and in structured bullet form.

Questions to address:

1) **Comments on: The overall approach to the specified modeling purpose and the particular methodologies chosen to achieve that purpose;**
   - This model fills an important need for an independent capability to assess how manufacturers might respond to GHG emission regulations on light-duty vehicles.
   - There is much to recommend this model, which grapples with some key challenges of assessing how progress toward tighter fuel use or GHG emissions standards can be achieved through incremental vehicle technological change, and at what cost.
   - The essential approach of this model is consistent with others in a similar vein, with the most notable predecessor being the NHTSA "Volpe Model." It describes the set of technological possibilities for improving vehicle fuel economy, or reducing GHG emissions, characterizing for each technology the cost and incremental change in emissions and fuel use. It determines a sequence of introduction for fuel-economy (or fuel switching) technologies necessary to meet a fleet-average CO2 emission constraint for each manufacturer. However it differs from some other approaches in significant ways:
     - 1. The sequence of discrete technologies that can be used for any single "Vehicle Type" is *exogenously* specified by the user. Those fixed technology successions *t*, *t*+1 … for each vehicle type *v* ,essentially define a vehicle-type-specific supply (marginal cost) curve for emissions reduction. The model determines the sequence in vehicle types each separately progress in an orderly fashion down their emissions reduction technology curve.

- o 2. The model makes vehicle technology redesign decisions not annually, but for each vehicle "design cycle," which is typically specified as a fixed number of years.
- o 3. The algorithm does not do a simultaneous choice of the set of technologies that minimize vehicle net costs such that the GHG emission standard is met. Rather it iteratively "dispatches" discrete new technologies by choosing which vehicle is to progress next by one more step through its sequence of technologies. It repeats this dispatching over vehicle types until the fleet average GHG emission standard is finally met. The choice of which vehicle type is to receive more advanced technology is based on one of two figures of merit, called "TARFs."

- It is wisely stated that effective model design hinges on a careful definition of its purpose or purposes, and an acknowledgement of its bounds and limitations. The documentation could be much strengthened in this regard. Here is my impression of its suitability:
  - o This model is currently most suited to estimating the incremental net technological cost of any single manufacturer achieving various GHG emission levels, specified as an average for that manufacturer's new-car fleet. It accounts for technology costs and lifetime fuel cost savings in its dispatching of technologies for each manufacturer's fleet. Other attributes and societal impacts may be monitored *ex post* (e.g. the extensive and somewhat disparate list on the top half of p. 3, including criteria pollutant emissions, noise, congestion, refueling time, etc.) but these are *not* considerations in the model's solution, i.e. in the core algorithm that sequences the application of vehicle technologies.
  - o A compact way to describe the models approach is that, like the Volpe Model, its solution has two phases: "manufacturer compliance simulation" (with cost-based technology choice) and "effects estimation" (based on a diverse set of *ex post* calculations).
  - o The model does *not* project vehicle sales, or sales mix, or aspects of vehicle design and vehicle appeal to consumers, apart from altered lifetime vehicle capital and fuel use costs. This is not mentioned as a flaw, but as an important design choice that should be stated. Large changes in fuel economy and GHG emissions could have important indirect impacts on the design and appeal of the vehicle, particularly if tradeoffs are made in the areas of vehicle size, weight, performance, range, and, for alternative fuels, fuel availability and convenience.
  - o The model treats each manufacturer's regulatory attainment problem independently, and is not currently designed to model "flexible" emission standards that allow permit trading among manufacturers, permit banking or borrowing, or economy-wide GHG trading systems.
- Suitability of method
  - o To some extent the discussion of the manifold ancillary benefits and costs can be a distraction, since a coherent and complete framework for their endogenous analysis is currently outside the scope of this model. I suggest that the model developers may wish to stay focused first on clearly and rigorously modeling the fuel-economy technology choice and cost-effectiveness considerations, for various GHG emission levels. Where possible, one reasonable design approach

might be to assume that other vehicle attributes are essentially held relatively constant, for each vehicle size and type.

  - Overall, the model documentation suggests that model developers may be hopeful of doing too much soon, with many (over 10) stated intentions for future extensions. Better and sounder results may follow from strategically limiting the model scope, carefully testing the model (in full, with real datasets), and then selectively adding features over time.
  - One feature of this model approach is its comparative analytical simplicity but heavy reliance on specialized data inputs (discussed further in Item 2 below). This should be viewed as a model strength: its contribution need not rely on analytical sophistication, but also on the coherent application of good quality, widely reviewed data.
- Two major methodological points:
  - In any model, particularly any model of markets with social externalities and government intervention, it is essential to be very explicit about *whose* behavior and objectives are being modeled. Otherwise there is danger that nobody is really being described, or that we might impute particular knowledge and incentives to market actors who actually have neither. Naturally a model can be both normative, saying what should be done optimally, or descriptive, saying what we think will be done by some actors in certain circumstances even if it is not clearly optimal. And it can apply to what would or should best be done for different agents: vehicle consumers, manufacturers, or the government/society as a whole. I am a little unclear about whose behavior is being modeled in the succession of technology decisions made. It appears the intent is to model market behavior of competitive vehicle manufacturers facing cost-minimizing consumers and a firm-wide emission constraint. But the objective of such a firm is not explicitly stated, and the solution rules are not clearly mapped to that objective.
    - In this matter it seems that the Volpe Model has set a good example by succinctly and specifically stating up-front whose behavior is being modeled: "The system first estimates how manufacturers might respond to a given CAFE scenario, and from that the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities." [P. 1, http://www.nhtsa.gov/staticfiles/DOT/NHTSA/Traffic%20Injury%20Control/Articles/Associated%20Files/811112.pdf]
    - Would a similar description not also apply to the EPA GHG model?
  - Given this idea of modeling the behavior of particular actors, e.g. manufacturers, in mind, the objectives of the actors should be reflected in the solution method or optimization condition. Bearing this in mind, there are some concerns with each of the two TARFs proposed as technology-dispatching figures of merit.
    - The "EffectiveCost" TARF is essentially the cost of each technology net of its discounted lifetime fuel savings (omitting the problematic "FEE" component, which seems mis-specified). Arguably, minimizing this would be a correct objective of new-vehicle consumers who discount fuel

savings in the same way and given no change in non-cost vehicle attributes. This could also be the objective of competitive firms acting on behalf of prospective consumers. In a mixed integer program these costs would be minimized *subject to* meeting the emission standard, and the algorithm would choose the least cost combination of technologies. The possible problem is that the EPA GHG Model algorithm sequentially dispatches new technologies in order of EffectiveCost, but without regard to their effectiveness in reducing GHGs. Some technologies with low net-cost could do little for GHG reduction. In the limit a low EffectiveCost technology, say using a high-GHG alternative fuel could even increase GHGs (FFVs with coal-fired corn-ethanol?). Regardless, there is no assurance that the suite of technologies finally assembled to reach the GHG standard in this way would be the low-cost suite. The authors may wish to consider when they recommend that the first, EffectiveCost TARF, is appropriate.

- The "CostEff" TARF on the other hand leads to an algorithm sensitive to both cost and cost-effectiveness for GHG reductions. Such a cost-benefit ratio can lead to optimal selection rules for packing (knapsack or budget) problems. But some confusing terms are included in the TARF, most notably the non-standard way in which VMT is discounted for the purposes of this TARF (See equation top of page 11, line 1). The inclusion of "IR" ("the annual increase in the value of CO2") in the discount factor is done without explanation or justification. While the term IR is never really defined (is it meant to be the growth rate in GHG damages, abatement cost, or a CO2 tax?). It inclusion seems to conflate considerations of social benefit (value of GHG avoidance over time with cost (of technologies). The vehicle manufacturer's cost of GHG avoidance is already embodied in the TARF numerator. The denominator should perhaps only reflect the quantity of GHGs avoided. As currently written, this CostEff TARF would not seem to be a consideration for vehicle manufacturers whose objective is to produce a new-car fleet meeting consumer needs and a GHG emission standard at least cost. What objective was intended with this hybrid aspect of the TARF?

- There are other important methodological points to raise, that are discussed below in Section 3 on conceptual algorithms.
- At this point, please allow an extended comment on the model documentation. Clearly it is in draft form only, and there would be much benefit from improving and clarifying it. This is not simply a matter of fastidiousness, but is an essential aspect of making the intellectual case for this model. As it stands, understanding the model was much more work than need be. Some specific suggestions are:
    - Restructure the presentation, perhaps following the pattern of a journal article. (E.g., begin with stated purpose and background. Place this model in the constellation of related models and indicate what is different and why. Describe approach, data sources. Sample results.)

    - Bringing description of the "Core Program" and what the model does toward the front.
    - Clarify and condense the model description. Classically, this would involve:
        - State model objective (typically stating what is maximized, minimized, or what final solution condition is sought)
        - State model constraints
        - State and discriminate between principle decision variables, exogenous inputs, parameters, and internally calculated results. (This is not done in the variable list of Appendix 6, which also is incomplete. It omits AIE, PF, CAP, TCO2, IncrementalCost, TechCost, TARF, VMT, SurvivalFraction, AnnualMilesDriven, Leakrate, RefLeakage).
        - State the solution algorithm and termination condition
    - Rigorous use of notation. Currently, for example, the subscript *i* usually refers to "year" (eqns on page 10 and 11) but sometimes indexes technology (eqns at line 10 on p.12).
    - Use consistent variable names. For example, on pp. 16 and 17, it appears that the same variable is called "ModelSales", "Sales,", and "Annual Sales."
    - Clarify subscripts and carefully apply them. The principle subscripts that seem to apply are:
        - t: technology number in sequence for each vehicle type
        - i: actually vehicle *age,* which is to be distinguished from year
        - y: year (which indexes, eg. fuel prices)
        - v: vehicle type
        - m: manufacturer
        - For example, equation at bottom of p. 12 is missing subscripts on AIE and RIE (presumably *t),* while GWP in that equation is indexed by technology t yet elsewhere (e.g. middle of page 11) it is not.
    - Carefully state units. Physical equations cannot be fully understood without a statement of the dimensions. For example, the equation in the middle of page 11 can be more readily understood if "Leakrate" is known to be in [g-GHG/yr], not [g-GHG/mi].
- Overall, the authors might wish to look at the documentation of the NHTSA Volpe model as a helpful template.
    - That documentation is actually reasonably compact (35 pp plus an extended guide to operation).

- It gives an excellent, succinct prose summary of what the model does in the first 3 pages (1-3), and much of the wording might be applicable to the EPA model.
- It clearly states what is being modeled:
- There is a flow chart and a technology sequencing flow chart
- Equations are then presented in orderly manner with consistent notation and subscripting.

2) Comments on: The appropriateness and completeness of the contents of the sample input files. (EPA staff are not seeking comment on the particular values of the contents of the input files, which are samples only.)

- First, an overall point on data. While the instructions urge reviewers to not consider the particular values of sample data, it must be born in mind that models are essentially datasets, the equations which link the data, and the algorithms for achieving the solution of those equations. In this case the model equations (in the documentation) are reasonably straightforward, although the algorithm for their solution is somewhat opaque (not explicitly stated and embedded within a compiled module). Assuming a reliable solution algorithm (something hard to test in this review and with limited data), model quality will then depend strongly on the quality of model data. This is particularly worth mentioning because many of the data needed for this model are not readily available from established sources. The model calls for detailed, specialized, knowledge about vehicle technologies, their costs, incremental contributions and interactions, their availability over time and across vehicle types, *and* the data-providers must determine the sequence of technology application within each vehicle type. Ultimately, this dataset is likely to be the most valuable and significant component of this model. Particularly if it becomes publicly available, and serves as a standard. Thus the data issues should not be minimized.
- In all data input files, it would help minimize errors if units were specified. Kilograms or grams, etc. The "Fuel" datasheet does not indicate the unit for price ($/gge, in nominal $?. What are the units for electricity?)
- The "Data Validation" capability and error report is a very useful feature. Ultimately the modelers may wish to error check almost all inputs for acceptable range, if that is not already done.

2a) The elements of the Market input file, Appendix 1, which characterize the vehicle fleet;

- This file describes vehicle sales by manufacturer and vehicle type, and provides the attributes of those vehicle types.
- No specific comments at this time.

2b) The elements of the Technology input file, in Appendix 2, that constrain the application of technology;

- As discussed above, this could be said to be the heart of the model. It requires both detailed technological knowledge *and* considerable judgment about the sequence, timing and impact of each technology.
    - It may be worth a special task just considering what range of technology attributes can reasonably be specified, even by a technology or industry expert.
    - The possible strong-sensitivity to data specification may also call for formal method of risk or sensitivity analysis, given limits on the ability to refine the data.
- How are technology interdependencies across vehicle types represented? Given outsourcing and the cost reductions from component sharing, would the application of a technology for one vehicle type make it more likely to be applied to another vehicle type? I could not discern how such considerations are represented in the data, and reflected in the solution algorithm, if they are.
- The data challenge is even greater if the stated goal of representing technological learning is pursued. While ultimately technological progress (through autonomous gains from R&D, scale economies and learning-by-doing) should probably be acknowledged in a later model version, benchmarking that progress is never easy. Moreover, technological learning and progress will be a function not of choices for each Vehicle Type (as the spreadsheet organizations suggests), but of industry-wide developments across vehicle types and manufacturers.
    - In our models on new vehicle technology introduction, we have found it useful to distinguish between 3 types of technological progress: autonomous progress over time due to R&D; progress or cost reduction due to production scale (units produced per plant); and progress from Learning By Doing (LBD). All three of these play a role, but the proper benchmarking of each is quite challenging. I agree learning should be approached, but cautiously because its specification and parameterization can have such a pronounced effect on model results.
- Spot-checking these entries, I did not see any items associated with changing vehicle size and weight. This may be a design choice rather than happenstance for the sample data: technologies that substantially change the vehicle design and hedonic attributes for the consumer would call for a more rigorous assessment of net-value to the consumer, and a potential re-statement of objective (TARF sequencing rule).

2c) Scenario input file, definition of the standard and economic conditions (Appendix 3)

2d) The elements of the Fuels input file, Appendix 4

- This list does not yet reflect biofuels or renewable fuels, which are a growing consideration, in no small part due to recent law and EPA RFSs.
- Some provision may be needed for the variable energy and GHG content of gasoline, as the ethanol content varies over time.
- Provision may also be needed for E85, and the uncertain fraction of E85 use by FFVs.
- The net fuel economy and emissions by PHEVs remains an area of continued study. EPA is well aware that fuel use by fuel type and resulting emissions depend on PHEV design (AER), consumer use patterns, time of recharging, and the fuel used for regional grid generation. Nonetheless, some simplified representation of the

alternative PHEV designs will be needed soon. I was unable to ascertain what progress EPA has made in this area.

2e) The reference data contained in Appendix 5. (Implied flexibilities and constraints of the model)

- No specific comments

3) The accuracy and appropriateness of the model's conceptual algorithms and equations for technology application and calculation of compliance;

- Equations for technology application:
  - The sequence of technology application, and timing and extent of application, for each vehicle type, is exogenous.
  - Modelers acknowledge that "This approach puts some onus on the user to develop a reasonable sequence of technologies." As noted, the onus may in fact be quite substantial. Therefore, it is helpful that the model "produces information which helps the user determine when a particular technology or bundle of technologies might be 'out of order.'" [p. 7] Any such capability to assist the user with stage-1 exogenous technology sequencing for individual vehicle types is worthy of further development and greater prominence in the documentation and model.
  - The Volpe model seems to currently offer more facility for specifying the structured sequences introduction of technologies or groups of technologies. The EPA GHG Modelers may also wish to develop some tools that make it easier for users to group and sequence technologies, perhaps even with logical diagrams that map to or from the Technology.xls dataset. This would help experts represent their best judgement about technologies can or would be applied.
  - While this model allows for substantial technological detail, there will always arise further, potentially important, complexities. In this review I could not determined the degree to which the model can account for cross-vehicle-type, or cross-manufacturer, interactions in the selection and sequencing of technologies. For example, various forms of hybridization are mentioned as technology options. We already see that one manufacturer, Toyota, develops a hybridization technology for one vehicle it quickly spread to other vehicles from that manufacturer, and that same technology is also sourced to other manufacturers (Nissan). Can this be represented in some way?
  - P. 17 says: "Finally, the model determines the order in which technology packages are added to vehicles. The model first compares the TARFs corresponding to technology package 1 on all of the different vehicle types in the fleet and chooses the combination with the lowest TARF."
    - What does "combination" mean here? I understand it to mean the model chooses a combination (pair) of particular vehicle v and technology step t (advancing from t-1 to t).
  - Technical points on the TARF-based rules for technology application (Equations p. 14):
    - As mentioned, net cost ("EffCost") alone would not seem to be adequate for sequencing GHG-reduction technologies

        - The inclusion of a FEE for non-compliance has some issues (admittedly, the Volpe Model does something like this as well, but the justification is not compelling):
            - It embeds the cost of non-compliance in an algorithm that ends only with compliance. Hence the fee should ultimately be zero. Is the intent here to employ some sort of penalty-function based algorithm for constrained optimization?
            - "Non-compliance" is a manufacturer-wide condition, and cannot be associated with a specific individual vehicle or technology (Note: I believe the TARF measures should be subscripted with m,v, and t, to highlight that they are specific at that level).
            - As written, the FEE is applied to the change in fuel economy (mi/gge, MPG) for that particular technology step. This is not a measure of non-compliance, and its essential effect is to exaggerate the relative importance of fuel savings. Note that the fuel-savings term is proportional to (FC_{t-1} - FC_t) while the Fee term is proportional to ($1/FC_t – 1/FC_{t-1}$), essentially a monotonic non-linear transformation of fuel-savings. So even though there will be compliance an no fee, the effect will be to boost the weighting of fuel savings in a non-linear way.
        - A maintained assumption is that fuel economy technology will not alter sales volume or share. But does or could vehicle sales volume influence the choice of technology introduction? I only noted "Sales" being referenced in the post-processing calculations, and it is used in the tests for compliance. But sales is not a consideration in the TARF for a vehicle-technology pair, nor in the terms leading up to it, so the technology sequencing is based entirely on per-vehicle cost analysis. This approach is taken in other models and is not unreasonable. But if technology learning or scale economies matter, for example, the choice of which vehicle to apply the next technology to could be related to the sales volume of particular vehicle-types.
        - As mentioned, the non-standard adjustment of VMT discounting in the denominator of the CostEff TARF should either be eliminated or more explicitly and rigorously motivated. As it stands it seems to either mix social benefits of GHG reduction with the manufacturer's objective of meeting the emission standard.
    - On p. 13, the equation for Fuel Savings (FS) seems to be in error. Fuel price (FP) is divided by *i,* which denotes the age of the vehicle (year after its production). Is this simply a typographical error and a discount factor was intended (e.g. $(1+DR)^i$?)
        - In all cases where the lifetime value of fuel savings in considered, the challenge is to be clear about whose valuation of fuel savings is being calculated. It is widely observed that consumers, when making new vehicle purchase, may "undervalue" fuel savings either with a higher discount rate or a short planning period than actual vehicle operating life. I understand that these issues are probably behind the formulation used

here, but it would help to be more explicit. If manufacturer decisions are being modeled, the relevant question seems to be "How many years of discounted fuel savings would the manufacturer assume it will be able to recover from the consumer through the vehicle sale price?"

- Calculation of compliance to Attribute-based standards:
  - An overarching feature of the methodology is that progress in reducing GHGs/fuel-use occurs by advancing drivetrain technology and other attributes largely transparent to the consumer. Technologies are sequenced based per-vehicle figures of merit, assuming no impact on vehicle designs (apart from fuel use technology) and constant vehicle sales shares. One issue to consider is whether these assumptions of unchanged vehicle and unchanged sales mix become less defensible for attribute standards like the footprint standard.
  - On page 7, equation for the logistic-based footprint, there appears to be a sign error in the denominator (should be 1+exp((x-C)/D) not 1-exp((x-C)/D)). This is likely a typo in the documentation alone.
- Calculation of compliance to possible market-based standards
  - No discussion or provision for market-based (permit trading) standards is yet made. This should at least be acknowledged.
  - One strategy for doing more flexible standards would be to simply merge the datasets and technology-sequence stage for all manufacturers and vehicle types in a trading group. However, this would not provide information about potential permit prices and burdens across manufacturers.

4) The congruence between the conceptual methodologies and the program execution (examining the results with good engineering judgment)

- This is difficult to assess and a careful validation of this model's execution would require further examination. The results appear generally reasonable, but that is a weak test.
- I was only able to experiment with cases for one design cycle. The longer-term cases involving multiple design cycles are more challenging. It has been noted the model solves for design cycles independently of one another. So it would be worthwhile to test what this implies for the sequence of technologies used from one cycle to the next.
- One observation is that the inclusion of the non-compliance FEE does affect the model solution and choice of technologies. As mentioned above, the theoretical justification for this is not well formed, given that all manufacturers are typically assumed to end in compliance. However, I did not that the impact of including the FEE is modest, only changing per-vehicle costs by a few dollars. However, for at least one manufacturer (#9) the cost and technology sequence changes significantly. I am not sure this is a desirable outcome.
- Also, simple tests with the sample dataset show a relative insensitivity to the choice of TARF. This was surprising, and needs more investigation.

5) Clarity, completeness and accuracy of the calculations in the Benefits Calculations output file, in which costs and benefits are calculated;

- This system produces a large number of useful side calculations.
- Again, further investigation is necessary to investigate their accuracy.

- Overall, a careful independent validation of the two phases of this model's execution (manufacturer compliance simulation and effects calculation) would be well worthwhile. The code for compliance simulation is compiled and not visible. Working through the logic in the post-processing calculations of the BenefitsCalculation spreadsheet would take a bit of time. But it would be worthwhile. Overall a useful validation effort could probably be complete in about a week of focused attention.

6) Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed; and

- The XML format for data transfer and display is a very good design choice, allowing flexibility, modern data-exchange capability, ready output to internet, and easy extension of the report.
- This display in the visualization output is useful overall, but it seems more oriented toward "expert users" who are willing to wade through details to find understanding and the information they need.
    - TechPack are reference by number only, but perhaps could easily be labeled with the full name or 4-character abbreviation, or cross-reference by hyperlink to a description of the technology.
    - Additionally, hyperlinks could be added that would allow the user to easily jump to the table for a particular manufacturer or vehicle type.
- It would be very helpful to have some graphical summaries of the input and output results.
- All output files should embed clear documentation on the inputs used. E.g.
    - The .log file does list names of the 4 input files, which is essential.
    - The "Visualization Output" file does not (yet) report the input files (but the information could be retrieve from the XML file).

7) Recommendations for any functionalities beyond what we have described as "future work."

- Clearly defined improvements that can be readily made based on data or literature reasonably available to EPA
    - First I note that there were multiple references to "future work." It may be helpful for EPA to construct a list of these prospective improvements, and establish priorities and a staged, progressive approach for revision. Specific releases of the model with carefully specified functionality will allow prospective users at EPA and elsewhere be clear about what the model is and can do at any point in time.
    - While the model has a number of valuable aids to execution and reporting (input validation, automated generation of run logs, XML data, and "Visualization" tables for web/browser display), more could be done here to improve usability and provide greater insight about each case run. Comparatively simple revisions and extensions to the operational procedures and output could be well worthwhile.
        - Provision for side-by-side case comparisons, reporting or graphing difference.
        - Case management and logging facilities.

        - Currently the system labels every file with generic name concatenated to a time-date stamp. Very quickly a directory can be cluttered with cryptically named log, xml, htm files.
        - A case archiving facility, that compresses all input and output files to document the case, might be useful
        - The ability to specify a CaseName in the Scenario file, that then becomes part of each output file, would also be helpful.
        - When the VGHG.exe file reads a scenario file, it does not record, or at least display, the name of the file read. It is easy to forget which case was read if you step away, or are doing many cases.
        - Relatedly, the purpose of the VGHG.exe's separate menu options is not yet clear to me.
            - It seems that once a scenario and the associated datafiles are read, execution would be the logical next step. The scrollable tables from data input are really too constrained a view to allow useful review or verification of the data.
            - Once the case is run, it seems "Save" to XML might be automatic, otherwise one is limited to the text-based log files, that omit summary information. "Saving" seems needed for Visualization and Benefits Calculation in the spreadsheet.
            - So perhaps VGHG.exe might load-run-save in one step, although I may be missing something important.
    - Graphical capabilities [more thought required here about exactly what graphs would be most useful. But there are many data in the tables, and they are not simple to process mentally.]
- Improvements that are more exploratory.
    - Extension to accommodate flexible/market-based emission or fuel-economy regulations.
        - Permit trading extensions, constructed by pooling selected vehicle types/classes, and/or manufacturers, during the compliance phase of the analysis.
        - Ex post calculation of implied permit prices based on marginal costs of compliance (measured by the cost/GHG reduction of the final technology pack applied).
        - Ex post calculation of economic implications for individual manufacturers, by comparing results with and without trading/pooling, and accounting for the implied costs and revenues from permit exchanges between manufacturers.
    - Extensions to consider endogenous (standards-induced) changes in vehicle attributes. These are a higher challenge, but would be very valuable for an improved understanding of the market responses to regulations.
        - Endogenous changes in sales volume/mix
        - Endogenous changes in vehicle size/footprint

Appendix D-13 Paul Leiby Review

APPENDIX E

JONATHAN RUBIN’S REVIEW DOCUMENT

Review:

Vehicle Greenhouse Gas Emission (VGHG) Emissions Cost and Compliance Model

Jonathan Rubin

23 September 2009

Dear Sir/Madam:

I would like to congratulate the EPA for undertaking to build this tool which will be very useful for possible regulatory compliance and anticipated and unanticipated policy analyses. The construction of such a tool requires extensive expertise, professional judgment, necessary compromises and assumptions. The validity of the output will of course depend on these factors as well as the data available to populate the model.

My comments are based on my review of the materials provided to me by Southwest Research Institute: the EPA vehicle GHG Emission Cost and Compliance Model Description and associated attachments and appendices and the VGHG model and the associated spreadsheets. These comments reflect my understanding of EPA's possible use for this model for regulatory compliance as well as use by external researchers and policy analysts who may use the model for analyses of state and regional policies.

My comments below respond to the particular questions posed in the transmittal letter from Southwest Research Institute.

Overall Approach to the specified modeling purpose and the particular methodologies chosen to achieve that purpose

The authors have clearly put in a great deal of work on this challenging project and should be commended for an excellent start. That said, more effort and thought needs to go into what I call the accounting stance. On page 2, line 42-43 (p. 2, l. 42-3) the documentation states that "The primary cost of the GHG emission control is the cost of the added technology compared to the baseline." My question is: "cost to whom?" Costs to consumers will differ from costs to society or costs to manufacturers. At times, the documentation reads as though these are costs to manufacturers – since CAFE fines are considered; other times the costs seem to be towards consumers or society. These accounting stances will differ for several reasons: 1) private and social discount rates differ, 2) social and private risk differs (on average technology performs as well as expected, but not for each vehicle), 3) subsidies to purchase plug-in vehicles or other advanced technology vehicles drive a wedge between private and social costs, 4) subsidies to biofuels and electricity at the state level (exemption for some or all road-use tax) mean that consumer costs are not equal to full resource costs. Clarifying the accounting stance is a high priority, because many further calculations rely on its clear definition.

Since the potentially regulated agents are vehicle manufacturers, my recommendation is to define costs as the costs to manufacturers of incremental technology and vehicle re-design costs. The net costs to manufacturers are equivalent to the incremental costs of fuel economy technology less any increase in retail prices that manufacturers can charge for more fuel efficient vehicles. This should be equal to some portion of the expected fuel savings plus any changes in the hedonic value of vehicles due to changes in vehicle performance, noise, size, and refueling time (more on this later). By separating out manufacturing costs more clearly from consumer valuation of vehicles, the presentation will be more transparent. This also will make clearer the distinctions between consumers' rates of discount from manufacturers' costs of capital from society's rate of time preference.

Additionally, I recommend that the *net* costs clearly incorporate and identify all subsidies (for electric or plug-in hybrid vehicles and alternative fuels) but display costs and benefits separately to private agents (manufacturers, consumers) and society. These will generally not be the same. For example, the benefit calculation spreadsheet "Externalities" adds together consumer money saved on fuel with savings from lower oil imports. I would be very surprised to learn that the assumptions of the discount rate or risk premium or both in the calculation of benefits of reduced crude oil imports are the same as consumers' discount rates for expected future gasoline savings.

2) The appropriateness and completeness of the contents of the sample input files.

a) The elements of the Market input file, as shown in Appendix 1 of the model description, which characterize the vehicle fleet

If the data are available, it would be useful to have the cross-price elasticities for makes and models or model segments such that mix-shift impacts could be taken into account as vehicle prices rise in response to additional technology packages.

Some of the market data are interesting, but do not seem necessary. For example, what is the use of knowing a vehicle's structure (e.g., unibody) or the maximum seating capacity?

Does the market spreadsheet contain data for mid-size trucks, gross vehicle weight 8,500 - 10,000? If not, I would think it should, given that they are now covered under the revised light truck CAFE rules.

b) The elements of the Technology input file, in Appendix 2, that constrain the application of technology

Are the incremental costs shown in column X retail or wholesale? What do they assume about the volume of production? If I read the file correctly the incremental price for plug-in hybrid technology often has a low first cycle cap of 5%. Is the incremental cost of this technology consistent with its use on 5% of a market segment of a given manufacturer? It is important to clearly define the relationship between scale of use and incremental technology cost. The columns "a", "Decay", "seedV", "kD", and "cycle learning available" need further clarification.

P. 2, l. 14 notes that the GHG target can be set as a function of vehicle footprint. The technology input file does not show an indication of how down-weighting and changes in footprints may be used to meet a set of given standards. This may not be able to be accomplished immediately given available data, but it should be considered as more experience with the footprint standards is gained from CAFE compliance.

c) The definition of the standard and economic conditions in the Scenario input file, as shown in Appendix 3

As per my earlier comments, I think there ought to be a place for 3 different discount rates: consumers, manufacturers and society. Similarly, their ought to be a places for payback periods for consumers and society.

d) The elements of the Fuels input file, as shown in Appendix 4, which characterize the fuel types, properties, and prices

It would be useful to reference the data sources for many/most of the data items. For example, energy density – please see EIA report XYZ. The value shown for gasoline, for example, at 115,000 is different than that published by the USDOE, *Transportation Energy Data Book* v 27 (Davis, Diegel, Boundy, 2008, Table B4), which shows a (lower heating) value of 115,400 Btu/gallon.

The units should also be displayed for all inputs. Again, using the gasoline example, being familiar with the data, it is clear that the unit of analysis is Btu/gallon (lower heating value). For other data, the units are less obvious. For electricity, the input file or the documentation, or both, should give the assumed conversions from kilowatts to energy density or motive energy such that users can adjust for different end-use efficiencies. Also for electricity, the assumed grid mix should be given with conversion rates such that users can make appropriate adjustments for different policy analyses.

I do not see a statement indicating whether the fuel price data is in nominal or real dollars.

I do not see a row for ethanol giving its energy density, mass, and density. I am assuming that fuel type "EL" is electricity. Also, should you not have at least two types of ethanol – corn and cellulosic – with different price paths?

As I indicated in my earlier comments, I think it is important to explicitly note the role of subsidies when determining costs. Given this assertion, the fuels data file ought to explicitly note federal and state average subsidies (i.e., the federal blender's tax credit and foregone state excise taxes) for ethanol and other alternative fuels. As I note below in 7) Extended Functionality, accounting for foregone taxes is a logical addition to the model, especially when considering plug-in electric hybrid vehicles.

e) The reference data contained in Appendix 5 which are currently hard-coded into the model but, in the very near future, will be contained in a user controlled input file.

The Exclusive Inputs spreadsheet anticipates E10 and E85. It would seem fairly straightforward to allow for other blends such as E15. The proportion of the ethanol that comes from cellulosic sources in each year should be accounted for such that upstream CO_2 emissions can be properly credited, similarly for petrodiesel and biodiesel.

3) The accuracy and appropriateness of the model's conceptual algorithms and equations for technology application and calculation of compliance;

On p. 9, l. 40, the documentation states: "The core model then adds the effectivenesses and the costs of the technology addition until each manufacturer has met the standard or until all technology packages have been exhausted." Given that existing law allows credit averaging across all vehicles sold by a manufacturer, this requires that compliance would be checked through an iterative routine. Please describe this routine including mechanisms to prevent cycling so that convergence is assured.

p. 10. VMT is given by: $VMT = SurvivalFraction * AnnualMilesDriven$. I believe this is this done by vehicle class (from the data file). The documentation should index the function with separate subscripts.

p. 10. Discounted VMT. I have two issues with this calculation. The first is mechanical. Why

$$VMT_{D,FS,i} = VMT_i \times \frac{1+\frac{DR}{2}}{(1+DR)^i}$$

does the numerator have the term 1+DR/2? Is the discount rate not understood to be the simple annual rate? (Also what do the indices D and FS represent?). Conceptually, however, I do not think this VMT should be discounted. Costs and benefits are appropriately discounted, but I think it is a mistake to discount a physical calculation. It blurs the distinction between consumer and society valuation of VMT and can lead to misleading outputs.

This point is further emphasized by calculation of VMT for GHG calculations (p.11)

$$VMT_{D,CO2,i} = VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}$$

, where VMT is enhanced by the rate in change in the value of CO_2, IR. I strongly suggest that this equation be re-done to separate out measurement of physical units (VMT) from cost and value calculations.

p. 11. RCO2

$$RCO2(g/mi) = \frac{\sum_{i=1}^{\substack{Lifetime\\(years)}} \text{RefLeakage}_i \times GWP}{\sum_{i=1}^{\substack{Lifetime\\(years))}} VMT_{D,CO2,i}} = \frac{\sum_{i=1}^{\substack{Lifetime\\(years)}} \left[LeakRate_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right] \times GWP}{\sum_{i=1}^{\substack{Lifetime\\(years)}} \left[VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right]} = \frac{LifetimeLeakage \times GWP}{LifetimeVMT}$$

I have two comments. First, it seems to me that, as with VMT, the numerator ought to be multiplied by the survival function. Second, as with VMT, the leakage rate ought not to be adjusted by DR and IR. Also, again, I do not understand the form of the adjustment – why multiply the numerator by 1+ (DR-IR)/2? Should not the GWP be indexed by i?

p. 12. Determine the order of Technology Application. On the previous page the subscript *i* represented "year" here it represents technology package. The use of subscripts should be unique throughout the documents.

P. 12. Intermediate calculations for each vehicle type. It appears that the subscripts have changed again. CO2 is indexed by t and AIE, RIE are missing subscripts altogether.

p. 13. Calculate the fuel consumption before and after technology additions.

$$FC_{t-1} = \frac{CO2_{t-1}}{CD_{t-1} \times \left[\frac{44gCO2}{12gC}\right]}$$

. Given that CD is in units of carbon, this equation looks unit-less (CO2/CO2). Where do gallons per mile units come in?

P. 13, l. 18. In step iii, calculating fuel savings we see the following equation.

$$FS = \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i}\right)_{t-1} - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i}\right)_t$$

First, why is FP divided by *i*? Second, where is the adjustment for vehicle age? How does this equation account for consumers' choosing to drive more miles using one fuel v. another? (Consumer's may want to maximize the time they spend in electric power mode.) Even if the data do not exist to parameterize the model yet, I suggest that the functionality be built in to allow for consumers' choosing to use one fuel type or another.

P. 20, l. 38-46. In calculating the impact of the reduced time required to refuel vehicles, I do not see a mention of the estimated driving that will occur using electricity in PHEVs.

4) The congruence between the conceptual methodologies and the program execution;

As suggested, I made changes to input values in the spreadsheets and re-ran the model. The changes as displayed in the benefits calculation spreadsheet were what I had qualitatively expected.

5) Clarity, completeness and accuracy of the calculations in the Benefits Calculations output file, in which costs and benefits are calculated;

Please see my comments in the beginning of the document. I believe that the benefits calculations should more clearly reflect benefits and costs to three different agents: manufacturers, consumers and the nation.

Recognizing that the benefits data (Benefits Calculation workbook) is subject to change, it would be really useful to list the data sources for all inputs. For example, if the VMT data is coming from MOBILE6, the VMT_Lookup spreadsheet should clearly state MOBILE6 as its source and similarly for the other inputs and spreadsheets.

Similar to the formula used to discount VMT, the spreadsheet "ExternalVMTCosts($)" discounts externalities using the formula: $\frac{1+\frac{DR}{2}}{(1+DR)^i}$. My question is why? Most commonly used discount factors are simple $\frac{1}{(1+DR)^i}$ annual rates. In some senses it does not really matter because the user can set the discount rate, but by using a non-standard discount rate this is likely to lead to unnecessary confusion.

In the "Benefits Calculation" workbook, the worksheet, "Emissions_Fuel Conservation" shows upstream savings from NOx, VOC, CO, PM, and SOx. These emissions savings are all calculated based on upstream conventional gasoline emission savings. I would think that either: 1) these should be based on a weighted average of gasoline, diesel, ethanol, and electricity upstream emissions, or 2) the gallons saved should have been weighted gallons. I cannot readily determine if the saved gasoline gallons are weighed by the proportion of gasoline, electricity, ethanol and diesel (and the weights would be emission-gallon weights.) This needs to be clarified or corrected.

In the "Benefits Calculation" workbook, the worksheet, "ExternalVMTcosts($)" displays the discount factor applied to future costs as the common discount factor used throughout the model. As I earlier suggest, society's rate of discount for accidents costs (human life) are not likely to be the same as consumers' rate of discounting future gasoline savings. These should be separate inputs.

In the "Benefits Calculation" workbook, the worksheet, "DownstreamCosts($)", the units on CO2 are shown as "$/ton". I believe that the label is missing the modifier, "metric".

In the "Benefits Calculation" workbook, the worksheet, "UpstreamCosts($)" shows benefits determined for CO, VOC, NOx, SO2, PM2.5 all based on emission factors for conventional gasoline. As per my earlier comment, I think these ought to use separate emission factors for each fuel.

In the "Benefits Calculation" workbook, the worksheet, "All Costs" shows costs in aggregate for the nation. It would be useful to also display the average, per vehicle costs.

6) Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed; and

In displaying the results Average Incremental Costs, please round to the nearest dollar; showing two digits to the right of the decimal point gives a false sense of precision and makes the output harder to read.

7) Recommendations for any functionalities beyond what we have described as "future work."

The model (VGHG) window box should be made larger – perhaps fill the screen. It is really too small to perform step 4 in running the model (i.e., Verify that the correct data has been populated into the VGHG model). There is also no side-to-side scroll to see the whole data field.

Given the renewable and advanced biofuel requirement in the Energy Independence and Security Act of 2007, it would seem that the model ought to have data input fields to allow users to specify the quantities (or proportions of total fuel) of ethanol and biodiesel used in each year. Moreover, the proportion of biofuels which come from cellulosic sources should also be able to be specified. Accordingly, the GHG emission accounting framework will need to capture that proportion of the reductions due to changes in vehicles and that proportion due to changes in fuels. In anticipation of future developments in the biofuels market, it may be worthwhile to build in placeholder functionality to account for domestic versus imported biofuels or biofuel feedstocks.

The model would be significantly enhanced if it were made probabilistic. Given that input data contains underlying uncertainty (What is the actual cost of a given technology? What will be the price of gasoline in 5 years?), the model should be made to run hundreds or thousands of times using Monte Carlo analysis on some of the key input data to generate a distribution of outcomes. Even if this is not done in the near term, having the output columns show results for “high and low” cost/interest rate scenarios would be convenient. It would save having to run the model multiple times and pulling the results in to some other summary worksheet.

The documentation notes (p. 2) that the primary cost of the GHG emission control is the cost of the added technology as compared to the baseline. I do not think this is a valid presumption for large changes in GHG emission control. The NRC’s study on CAFE assumed that vehicles were hedonically equivalent. Given the likely wide-spread adoption of diesel technology and, quite possibly, plug-in hybrid vehicles (PHEVs), vehicle driving experiences are not likely to be the same. Quite possibly, PHEVs will provide a superior level of driving satisfaction. If vehicle manufacturers downsize or reduce performance (acceleration) to meet compliance, vehicle satisfaction could diminish. I do not have a good suggestion on how to adjust for these possible hedonic costs or benefits. Perhaps the model could incorporate placeholder equations that would allow users to specify hedonic gains and losses. Nonetheless, the model documentation should be forthright in acknowledging this limitation.

The model should provide for an estimate of the likely gasoline excise tax implications for different levels of GHG emission reduction. Particularly useful would be to present this information in the context of different compliance strategies. For example, with tax credits for PHEVs, and no change in federal gasoline excise tax policy, the revenue losses could be significant. This functionality could be very useful for policymakers.

As described in the documentation, the model development foresees an increased ability for users to change input assumptions. Changes to these assumptions may have significant impacts on costs and GHG emission reductions. It would be useful for the Model Reference Guide accompanying this model to describe in qualitative terms the impact of or assumptions behind choosing to adjust certain parameters. For example, the user manual could indicate that lowering the years of payback for technology would be consistent with a view that consumers only value the first years of fuel economy gains or place little or no value on GHG emission reduction that occur near the end of a vehicle's lifetime. If practicable, it would also be useful to point out inconsistent choices.

It would be very useful to have the model output be available in units that are used internationally – grams CO_2 /kilometer or grams CO_2 equivalent/KM.

Clearly falling into the work for the future, would be to have a time profile of upstream CO_2 emissions for conventional gasoline and diesel reflecting regional or national low carbon fuel standards.

EPA Responses to Peer Review Comments

A. Comments by John German

Concepts and Methodologies Upon Which the Model Relies:

(A) Model structure

The model is an accounting model. This is neither good nor bad. The advantage is that it avoids overmodeling and embedding errors in the model itself. The disadvantage is that the factors affecting the results are all inputs to the model. This requires a great deal more sophistication and work by anyone using the model to prepare the inputs properly. It will also make it more difficult for anyone outside EPA to use the model, unless EPA is willing to provide the detailed inputs to other users.

With this type of model, it is essential that EPA release the data in the Technology and Economics input files and discuss them in the Notice of Proposed Rulemaking, as the real analyses and modeling are in these input files. But as long as this is done, the overall model construction is fine.

Response: EPA will publish all the input files in their entirety as part of its proposed GHG emission rule for model year 2012-2016 cars and light trucks (hereafter referred to as the "EPA vehicle GHG proposal" or "proposed vehicle GHG standards").

(C) Redesign cycles

I completely agree with EPA's logic in creating a model based upon vehicle redesign cycles. As EPA states, adding technologies incrementally to each vehicle model by model year does not add value to the model results. Using redesign cycles also allows for simplification of the fleet. It is impossible to predict the direction of vehicle redesigns for each manufacturer. It is just as accurate to assume, for example, that future mid-size cars from each manufacturer will be identical; as it is to assume that current differences in mid-size cars from one manufacturer to the next will be continued into the future. As a recent example, Honda left their compact crossover, the CR-V, virtually unchanged in size during the latest redesign. However, Toyota chose to lengthen their compact crossover, the RAV4, by 14" during its latest redesign. It is pointless to try to predict differences in vehicles from different manufacturers in the future and it is pointless to try to predict the exact year when redesigns will occur. This is a welcome simplification.

Another advantage of using redesign cycles is that GHG standards for interim model years can only be set, reasonably, as a straight line (or a constant % decrease) between the baseline year and the end of the redesign cycle. This is appropriate. Constant yearly % reductions provide a consistent signal to manufacturers for investment decisions.

However, there is one potential problem with using redesign cycles. It masks the investment needed to bring new technology to the market. The auto industry is extremely capitol intensive. Initial investment in a new technology is expensive, both for tooling and the resources necessary to assess (and fix) system-level effects and effects on reliability, durability, safety, and manufacturing. Redesign cycles tend to assess only the costs for high-volume production and skip over the high initial costs. Care must be taken to properly assess costs in the inputs.

Response: EPA agrees that capital investment is an important consideration when assessing the feasibility of GHG standards. EPA intended to include explicit accounting for and limitations in capital investment when developing OMEGA. However, this proved to be a difficult task and we decided to leave this until later versions of the model. The user can track capital investment outside of the model based on the types and levels of technology used. The user can also adjust costs upward during the interim years of a redesign cycle to represent the higher costs which are typical during technology introduction. EPA did this as part of its cost analysis for its recently proposed rule for the control of GHG emissions from cars and light trucks.

(C) Leadtime

The model handles leadtime issues far too simplistically. This was also a problem with the Volpe model. Leadtime is one of the most important issues in setting standards and one of the most difficult issues to assess properly. Thus, it is disappointing to see both NHTSA and EPA provide so little attention to the issue.

The only leadtime constraints in the draft model are industry-wide caps on the maximum technology penetration by redesign cycle and vehicle type. There are several problems with this approach:

- The largest problem is that it is inappropriate to treat all manufacturers the same. A manufacturer that has already invested in a particular technology in the baseline year will be capable of higher penetration rates than a manufacture that has never used the technology before – and also of producing the technology at lower cost. An obvious example is hybrid vehicles. Over 10% of Toyota's vehicles already have hybrid systems on them. After introduction of the CR-Z next year, Honda should also have more than 10% hybrids. Due to their experience and head start with hybrids, both manufacturers will be capable of much higher penetration rates than most other manufacturers. They are also further along the learning curve, so their costs will be lower. Similar situations exist with most technologies.
- Another problem is that costs will vary from manufacturer to manufacturer. As noted in my comments on redesign cycles, above, there are large upfront costs when a manufacturer introduces a new technology. For example, Toyota has already amortized large R&D and system-level costs for hybrid vehicles. They will be able to produce hybrids cheaper than manufacturers that are just starting to offer hybrids. The point is that the "Initial Incremental Cost" in the Technology Input File should not be applied to all manufacturers at the same time, but rather to each manufacturer at the time they first introduce a new technology.
- The third problem is that there is no such thing as a hard cap on technology penetration rates. There is a tradeoff that exists between cost and leadtime. Technology introduction can be accelerated by increasing investment – and cost and risk.

Long-Term Recommendation – The best way to handle leadtime constraints and technology penetration is to assess capitol investments by manufacturer. This would require adding a new section on capitol expenditures. In addition to assessing the cost of each technology, the capitol expenditure would also be assessed. Ideally, there would be two components to the capitol expenditure assessment for each technology, one for R&D expenditures for the first implementation of the technology and one for the capitol investment needed to add the technology to additional models. However, the second is more important. Each manufacturer would be assigned a total capitol expenditure budget for the redesign cycle and technologies could only be added up to the point where the sum of the technology capitol expenditures did not exceed the manufacturer cap. Alternatively, some increase in technology penetration over the cap could be allowed, but only if coupled with increasing technology costs. This would appropriately handle leadtime constraints and technology penetration rates.

Short-Term Recommendation – The long-term recommendation would require a lot of new work and is clearly not feasible in the timeframe needed for EPA's rulemaking. As a short-term fix, instead of using industry-wide caps on maximum penetration for each technology, EPA should:

(d) Set caps on the maximum increase permitted per year. This would be applied to each manufacturers' individual technology penetration; and

(e) Establish the model year for initial introduction. For technology that has not been introduced to the market yet, this year could be the same for all manufacturers. For a technology that is already being used by a manufacturer, the baseline year would be used for that manufacturer. However, if a manufacturer were not using a technology yet, even if another manufacturer is using it, a year of introduction would need to be set for that manufacturer.

(f) Some technologies would still need caps on maximum penetration. However, this should reflect market restrictions, not leadtime constraints. This would incorporate consumer values for particular technologies that go beyond just efficiency and performance. For example, even though manual transmissions are more efficient than automatics, most consumers will not give up the convenience of an automatic. PHEVs do not have much benefit for people driving a lot of highway miles each day. Diesels are desired for trailer towing and have advantages on highway fuel economy, while hybrids have advantages in stop-and-go driving. These types of market considerations can be handled by establishing maximum penetration caps, but they should be handled separately from how leadtime is handled by manufacturer.

Note that the yearly cap and introduction date violates the design cycle principal, but it is important to create the proper cap for each manufacturer and technology combination. Instead of using a model year for (b), above, the user could specify how many years into the design cycle a technology could be introduced.

Response: EPA agrees that the consideration of leadtime constraint is important. The current model was designed with the implicit assumption that the first year of the first redesign cycle being modeled was sufficiently in the future so that a manufacturer could completely alter the design of vehicles being redesigned in that year. For example, in EPA's vehicle GHG proposal, the first year of the redesign cycle was the 2012 model year. The start of this model year is approximately two years from the publication of the proposal and the final rule is not expected to be promulgated until sometime in 2010. Therefore, leadtime for the 2012 model year is quite short. Therefore, EPA adjusted the technologies caps for all technologies which might be restricted to years when a vehicle was being refreshed or redesigned to 85% or less, rather than the more typical 100%. This figure is based on an estimate of the percentage of vehicles which can be equipped with these technology packages from 2012-2016, though not in a linear fashion. Due to leadtime constraints, a lower percentage of vehicles was projected to be convertible in the early years than the later years of the program (i.e., redesign cycle). This is indicative of how the model inputs can be set in order to approximate leadtime constraints.

We also agree with Mr. German that leadtime is not a hard and fast concept and can be a function of cost (i.e., a manufacturer can shorten the required leadtime involved in making a technological change if it is willing to increase costs, though in the very near term there are real-world lead time constraints such as the time needed for construction of new manufacturering facilities or capital tooling upgrades). At this same time, coupling cost and technology penetration would be challenging to simulate in a model such as OMEGA in a way which addresses all the possible factors involved. Mr. German does not point out studies which estimate the degree to which costs might increase in return for shortening leadtime. However, if such relationships can be found, it may be possible to include such flexibility in the model when EPA adds the effect of learning into the cost estimations. At the present time, the model can be run with a series of scenarios, each of which contains varying levels of technology penetration and varying costs. The user can evaluate the results of these runs and determine which level of cost and leadtime is most appropriate.

We agree with Mr. German that manufacturers which have already implemented technologies such as hybridization have an advantage over those which haven't. It is probable that such manufacturers could hybridize a greater percentage of their fleet than other manufacturers. However, on a practical level, this advantage may not be that important to include in OMEGA at this time. Manufacturers which have already implemented technologies, especially major ones like hybridization, are generally in a better position to meet GHG standards than those which have not implemented such technologies. Thus, there would not be any practical change in the model's results if we allowed Toyota and Honda to have a greater hybrid penetration than applicable to other manufacturers, since these manufacturers do not require a greater hybrid penetration in order to meet the GHG standard. While true for hybrids, this relationship may not always hold true. We will consider moving the technology caps to the level of the manufacturer, or even the individual vehicle as we continue to develop OMEGA in the future.

If the user believed this factor was important and should be reflected in the model results, the user could simply group manufacturers by their estimated technology caps and perform one model run for each set of technology caps and then combine the results. To use Mr. German's example, vehicles produced by Toyota and Honda could be modeled in one run with high hybrid penetration caps and those of other manufacturers modeled separately with a lower technology cap.

This issue applies primarily to technologies which require sophisticating application at the vehicle or manufacturer level. Hybridization is probably the best example of this due to the complex integration of electric motor, battery and engine operation. However, there are many other technologies which may actually be purchased pre-assembled from a supplier, such as dual-clutch transmissions. Certainly having some experience with such technologies could increase the speed at which a manufacturer might be able to convert most or all of its vehicles to the technology. However, much of the experience is also being gained by the supplier and available to all manufacturers. The cost paid by each manufacturer may still be a function of sales volume, but this can be reflecting through learning factors when appropriate. Thus, we believe that this issue does not apply to most of the technologies which, for example, EPA included in its modeling runs in support of the EPA vehicle GHG proposal.

Regarding the variation of costs across manufacturers, this again will be addressed in large part when we incorporate learning into the cost estimation processes of the model. Currently, this can and has been done outside of the model.

EPA initially intended to incorporate capital costs into the core model of technology application as it began development of OMEGA. However, this proved difficult for several reasons. One, the number of units over which the capital investment should be amortized is not easy to determine. The model currently applies technology to either individual vehicles which could represent anywhere from individual vehicle models to vehicle platforms or all of a manufacturer's cars, for instance. Should the OMEGA model assume that only the sales of the vehicle being evaluated bear the burden of the investment or all the manufacturer's sales? Should sales over one or more than one redesign cycle be considered? Some technologies, as mentioned above, will be manufactured by suppliers. In this case, the capital cost will be borne by more than one vehicle manufacturer and so should be amortized over the sales of more than one vehicle manufacturer.

Our initial plan to incorporate capital cost and learning was to base technology ranking (and thus technology application) on the assumption that all the sales in a particular redesign cycle received the technology. Then, once the run was completed, the model would recalculate costs based on the actual application of the technology. This approach recognizes that no technology would be introduced if it was only going to be applied to a single vehicle. Costs for new technologies are always high early on, but manufacturers often do not fully recover their costs until the technology spreads to more vehicles. We will consider this approach, as well as others as we continue to develop OMEGA in the future. At the present time, the required capital cost associated with technology application can be assessed outside of the model. Should the results indicate that the required capital investment is inappropriate in some way, the inputs to the model can be modified to eliminate the issue.

(D) Technology Assessment

Requiring the user to input technology in rank order of cost-effectiveness is an interesting attempt to handle the synergy issue. Unfortunately, it fails to work in other ways:

- It only works if the learning rate is the same for all technologies and if no technology changes effectiveness over time. If one technology has a steeper learning curve than another, or if a technology increases benefits in the future, then the cost-effective order will change over time. For example, high-tech diesels are a relatively mature technology, as over 5 million per year have been sold in Europe for several years. Their future cost reduction potential is much less than that of hybrid vehicles, whose sales are at least an order of magnitude lower and which are still at early stages of development. Also, the high power Li-ion batteries just starting to penetrate the market will allow much smaller battery packs for conventional hybrids, with large cost reductions. In addition, analyses by MIT (2007) suggest that hybrid benefits will increase in the future as manufacturers figure out how to use the hybrid system to minimize operation at less efficient engine speed/load points.

- The synergies will differ depending on the specific technologies into which an individual manufacturer has already invested. For example, consider one manufacturer that has invested in MPI turbos and a second that has invested in DI naturally aspirated engines. If both manufacturers move to DI turbo engines, the first manufacturer will gain the benefits of DI adjusted for the DI/turbo synergies, while the 2nd manufacturer will gain the benefits of turbocharging adjusted for the same DI/turbo synergies. Thus, the synergy impact of DI/turbo must be assessed independently of each technology. Even if the model ignores the leadtime constraints imposed by baseline technology investment and assumes every manufacturer will adopt the exact same technology packages for a given vehicle type (not a good idea, as discussed, above), a problem still exists in backing out "any advanced technology that might have been present in the baseline" (page 12, line 3-4). In order to back out the baseline technology for different vehicles and manufacturers, the technology input file must contain independent assessments of MPI turbo, DI naturally aspirated, and DI turbo. The DI turbo line includes the synergies, but the other two lines do not. How does the model add them back in? If the turbo lines and DI lines occur before the DI turbo line, then the technologies will be added together first without consideration of the synergy effect.
- It does not allow for different markets for different technologies. For example, diesel engines have additional value for (a) customers who tow and (b) customers in rural areas. Towing is valued only by a small part of the market, but it is an important feature for that market. Customers in rural areas do a lot of highway driving and value the high efficiency of the diesel on the highway, while hybrids excel in urban areas. Thus, the markets for diesels and hybrids will be self-selected to some extent by their relative city and highway mpg, not the combined mpg used to select all technology.

In order to work properly, the model must be able to handle multiple pathways. For example, the model cannot allow turbo and DI benefits to be added sequentially, but must force each to go to a DI turbo input. A similar situation exists with the various variable valve timing systems and VCM. All offer primarily pumping loss reductions and all options must be present in the input file in order to back out technologies in the baseline. All these options cannot be added back by the model one after the other – the model must also be able to handle these multiple pathways. Another example is transmissions, where the input file must list 5-, 6-, 7-, and 8-speed automatics, as well as DCTs and CVTs (even ignoring manual transmissions). I could go on. The point is that I do not see how the model can avoid handling multiple technology pathways and depend only on the input order to handle synergies.

The model must also be able to handle technologies with different rates of change in benefits and costs in the future. This also requires that the model process the lines independently and not rely on the input order.

The market considerations could perhaps be handled with maximum penetration caps. For example, it could be considered that diesel engines will not compete well with hybrids in urban areas, so that the maximum penetration of diesels would be equal to their sale in rural areas plus trucks designed to tow, with the reverse true for hybrids. Of course, this will differ by manufacturer, which is a problem if universal caps, instead of manufacturer-specific caps, are maintained.

Response: Regarding Mr. German's concern that the technology ranking will change over time due to differing learning rates and changing effectiveness over time, it is not clear whether his concern applies to changes within a redesign cycle or across numerous redesign cycles. We do not believe that this issue exists within a redesign cycle. Certainly, technologies can differ in their learning rates and strictly speaking, this means that their costs change each year and this could affect the order of technologies. However, manufacturers focus on the mid to long term when redesigning their vehicles. Focusing on costs at the end of the redesign cycle is consistent with this. Technology rankings are more likely to change across redesign cycles. This can be accomplished in the current model by listing a specific technology twice, once in the correct position for one redesign cycle and second, in the correct position for the second or later redesign cycle. The technology cap for the first listing would be zero in the second or later cycle. The technology cap for the second listing would be zero in the first redesign cycle. Of course, this can only be done for a few technologies before the user runs into the limit on the number of technologies which can be handled in the model. If the desired order of technologies cannot be accommodated in this way, the model could simply be run with two separate scenarios, one for each redesign cycle with its own technology file. The results could then be combined in the same benefits calculation worksheet if calendar year impacts were desired. Since the core model of technology application starts over for each redesign cycle, the results of the scenarios evaluating the second or later redesign cycles would be exactly the same as a single, multiple redesign cycle run with that technology file. In future versions of the OMEGA model, it may be possible to provide separate effectiveness estimates for each redesign cycle, as well as separate technology order for each redesign cycle.

We believe that Mr. German's second comment above about dis-synergies is incorrect. In fact, the set order of technology application is what allows OMEGA to accurately estimate dis-synergies. This estimation is not in the effectiveness estimate included in the Technology file, but in the Technology Effectiveness Basis (TEB) for the DI Turbo technology which is input for each vehicle. To use Mr. German's example, let us assume that the effectiveness of turbocharging alone is 5% and that of direct injection 7%. However, combining the two only reduces CO_2 emissions by 10%. The effectiveness for DI Turbo technology in the Technology file will be the full 10%. Vehicles which already are turbocharged will have a TEB for the DI Turbo technology of 50% (5%/10%). Vehicles which already equipped with direct injection will have a TEB for the DI Turbo technology of 70% (7%/10%). The result is that the incremental benefit of moving the first vehicle to DI Turbo technology is 5%, while that for the second vehicle is 3%.

The advantage of the approach taken in the OMEGA model is that the technology path for each vehicle is fully known. The user can use any level of vehicle simulation modeling or vehicle testing to assess the overall effectiveness of the technology already on a vehicle and that which would exist after the application of each technology made available to it. At each point, the dis-synergies can be fully assessed because the full regimen of technologies on the vehicle is completely known. The TEB values in the Market File contain exactly the type of information which Mr. German says must be included. The only difference is that this information is in the

Market file and not the Technology file, to which Mr. German alludes. It is likely that this confusion arose due to a lack of clarity in our description of the critical role played by the TEB values in the draft model documentation provided to the peer reviewers.

Mr. German is correct in that OMEGA does not contain representations of distinct segments of the vehicle market (e.g., towing, rural drivers, etc.). However, OMEGA can still be designed to reflect such market segments if distinctions in the preferences or needs of these segments can be related to the acceptability of various technologies. For example, the need to tow can affect the acceptability of turbocharged downsized engines. The user can place vehicles which are used to tow trailers or haul heavy loads in different vehicle types from those vehicles which are not used in these ways. The technologies made available to vehicles with towing or hauling requirements then differ to the appropriate degree. A review of the lists of technologies made available to different vehicle types in the modeling which it performed in the EPA vehicle GHG proposal reflect such differences.

Another approach would be to limit the application of certain technologies to less than 100% of sales. For example, the user may believe that all electric vehicles would be acceptable to only 50% of the users of subcompact cars. Range limitations could severely limit their desirability to the remaining 50%. The user can simply set the technology penetration cap to 50% for the electrification technology for the vehicle type applicable to subcompact cars. The same can be done for factors which would affect the applicability or desirability of technology associated with rural driving, etc. Such limits would apply to all vehicles within a given technology type and thus, in general, to all manufacturers. If the user desires to limit the application of technology at the vehicle level, this can be approximated by setting the TEB and CEB values for that vehicle above the level actually present, so that the model will apply the technology to less than 100% of the sales of that vehicle.

(E) Maximizing Net Social Value

The model only outputs total costs and benefits. It presents these with great amounts of detailed information. But it is impossible to tell if the scenario has maximized net social value.

To put it another way, the model is only capable of counting up the benefits and costs of complying with pre-determined GHG standards. It is not able to do the reverse, which is to input the desired benefit and have the model determine the resulting GHG standard.

This is not a trivial issue. The 2007 EISA specifically mandates “maximum feasible” CAFÉ standards after 2020. NHTSA has long interpreted existing statutory authority to also require maximum feasible standards and established long ago that “maximum feasible” is determined by the point at which the costs of adding the next technology exceed the benefits. Even without a mandate, any credible analysis must be able to compare the costs and benefits of the chosen GHG standard to the maximum net social value.

Given the existing complexity of the model, it is not unreasonable for the model to also determine the GHG standard that maximizes net social value. The Volpe model calculates this point even with a much more complex model. EPA’s model will lose considerable credibility if it is not capable of calculating the maximum net social value point.

Response: We do not address Mr. German's comments about the need for either EPA or NHTSA to set GHG or fuel economy standards using a model which automatically identifies a standard which maximizes the difference between societal benefits and costs which can be estimated and monetized. These issues are beyond the scope of this peer review.

EPA agrees with Mr. German that it would be useful for OMEGA to be able to perform such a task. We have developed a spreadsheet which combines two of OMEGA's output files and identifies the level of GHG control which maximizes net societal benefits. The two files are: 1) the results file in text format which shows each manufacturer's emissions and cost after each step of technology application and 2) an abbreviated version of the benefit calculation file. The OMEGA model only needs to be run once with a GHG standard which is sufficiently stringent to require the addition of all available technologies to all vehicles. The spreadsheet adjusts each manufacturer's standard in a consistent manner off a predetermined universal or footprint-based standard until net benefits reach their maximum. EPA will consider publishing this spreadsheet once a set of instructions for its set up and use are drafted.

EPA will also add the automatic capability to determine the standard at which societal benefits are maximized to OMEGA at some time in the future. While such an approach can provide useful insight during rulemaking development., as Mr. German points out elsewhere, there are many factors, such as feasibility and leadtime, which are difficult to quantify and other factors which differ across manufacturers which are difficult to simulate in a model. One practical issue with model runs which maximize benefits is that they usually show that the standard is infeasible for a number of manufacturers with the technology that is projected to be available. Thus, EPA did not rely on the principle of maximizing net societal benefit in setting the standards contained in the EPA vehicle GHG proposal.

Appropriateness and Completeness of the Contents of the Sample Input Files:

(F) Market Input File

The market input file appears to be appropriate and complete – perhaps too complete in one way. The file contains separate inputs for reference case technology benefits and costs. The percentages in these columns should simply reflect the existing market penetration of each technology package. They should be identical for both costs and benefits. Is there a reason why these would be different? If so, the Model Description should explain this. If not, the duplicate columns can be removed.

Minor Suggestions:

- If the model wants to "back out" existing technologies, you will need a lot more than 20 columns to do this. You'll need 10 columns just to handle transmissions and another 10 just to handle different valve timing systems. Not to mention differing levels of high strength steel and aluminum use.
- The Model Description should state that vehicle types are a user input defined in the "Vehicle Type" tab of the Market Input File (I looked around for a while before I found this.)

- If you maintain separate columns for reference case technology costs and benefits, it would help the user to add a row above the existing descriptions and define columns AD-AW as "reference case benefits" and columns AX-BQ as "reference case costs".

Response: Mr. German's comments in this section (and our response) intersect with his comments in Section D. above concerning the ability of OMEGA to recognize and represent potential dis-synergies between technologies. First, the TEBs and CEBs in the Market file will usually differ. One reason for this occurs with technology packages which include several distinct technologies. Using Mr. German's example from Section D. a technology package might include both converting an engine to direct injection and adding turbocharging. If a baseline vehicle has a direct injection engine, but is not turbocharged, then the TEB would be the emission effect of only converting the engine to direct injection compared to adding both technologies. The CEB would be the cost of only converting the engine to direct injection compared to adding both technologies. Due to dis-synergies, as discussed in Section D. above, the emission effect of direct injection might be 60% of the total benefit of both technologies, while the cost might only be 50% of the total. In general, no two technologies will have exactly the same ratio of incremental cost and incremental effectiveness, which would be necessary for the TEB and CEB values for vehicles to be the same. Adding dis-synergies can markedly affect effectiveness, but generally has minor effect on cost. Thus, with dis-synergies, the chances of two technologies will have exactly the same ratio of incremental cost and incremental effectiveness in terms of the percentage of package cost and effectiveness is very small.

When Mr. German refers to the need for more than 20 columns in order to back out technologies, he again misunderstands the nature of the TEB and CEB values. (Again, this is likely due to a lack of clarity in the draft model documentation on this subject which EPA provided to the peer reviewers.) The units of the TEB and CEB values are the percentage of technology package effectiveness and cost which are already present on the vehicle. These percentages are best determined using a vehicle efficiency simulation model which can estimate fuel consumption over the certification driving cycles for various combinations of technologies. EPA's lumped parameter model is one example of this type of model, as is the Ricardo Easy5 full vehicle simulation model. The presence of individual technologies is not an input to the OMEGA model. As this is different from NHTSA's Volpe Model, this may be one of the causes of confusion.

We agree that the headings of the inputs files could be made more clear and descriptive. However, we have found that adding header lines to the input file has been more complicated than anticipated. Thus, we are taking the approach of adding more detailed descriptions of each column of each input file to the model documentation and directing the user to review these descriptions in order to obtain a fuller understanding of the nature of each of the inputs to the model.

(G) Technology Input File

As discussed above, the technology input files need to be substantially modified in conjunction with changing the model to handle multiple technology paths.

In addition, also as discussed above, the "Cap Cycle" numbers need to be replaced with generic caps on the maximum increase permitted per year and manufacturer-specific model years for initial introduction. The annual technology penetration increase cap would be applied to each manufacturers' individual baseline technology penetration, from the Market Input File, or starting with the manufacturer-specific initial model year for technology packages that have not been used yet by individual manufacturers.

The Average Incremental Effectiveness fields are fine, although, as noted above, if these change for future redesign cycles, the cost-effective order of the technology packages can also change.

I could not find any explanation of how the Initial Incremental Cost, α, Decay, seedV, kD, and Cycle Learning Available fields are used in the model. Even the detailed algorithms on pages 9-16 of the Model Description contain no reference to how technology costs are adjusted for the TARF calculations. Thus, I was not able to assess the appropriateness of these fields. However, in general, the cost reduction curve is not likely to be the same for all technologies. Some flexibility may be needed here.

The Technology Input File does not address weight impacts associated with different technologies. For example, both diesel engines and hybrids add considerable weight to the vehicle, which negatively impacts both performance and efficiency. It is possible to handle this off-board in the efficiency benefit estimation. However, if so the Model Description should explicitly state that weight impacts are expected to be assessed by the user and included in the technology inputs.

Response: As Mr. German alludes, several of the comments in this section have already been mentioned in earlier sections and are addressed there. Several of Mr. German's other suggestions would involve the model applying technology on an annual basis. OMEGA is explicitly designed to apply technology over an entire vehicle redesign cycle. This has received favorable comment from all three peer reviewers, including Mr. German. As discussed in Section C above, limits on the annual rate of technology application which the user believes apply can be input to the current model by simply summing up these limits over the redesign cycle.

Mr. German is correct that the draft model documentation provided to the peer reviewers did not describe how the Initial Incremental Cost, α, Decay, seedV, kD, and Cycle Learning Available fields are used in the model. These inputs are related to the prediction of cost reductions due to learning, which has not yet been implemented in the OMEGA model. These columns appear in the Technology file as place holders for future version of the model. The same is true for several vehicle parameters, such as weight, seating capacity, etc., which are included in the Market file. We will consider Mr. German's comment that the cost reduction curve is not likely to be the same for all technologies when we add learning to the model.

We agree with Mr. German that the impact of each technology on vehicle weight and performance should be included in estimating the effectiveness and cost of each technology. This is the approach followed in the EPA vehicle GHG proposal. We have modified the model documentation to clarify this.

(H) Scenario Input File

The compliance options – universal standard, linear attribute, or logistic attribute – are fine.

However, there are columns in the Scenario input file that are not described in the Model Description on page 6:

- TARF Option (column E) – Is this the "two TARF equations from which the user can choose", described on page 13? If so, should state this on page 6.
    - Why is the "Effective Cost" TARF equation limited to fuel savings over the payback period? Why aren't the discounted lifetime fuel savings considered? Is this done to try to mimic what technologies will be most acceptable to the customer? If so, this should be explained in the Model Description. I'm also not sure this is appropriate. Most technologies will be invisible to the customer. In addition, the primary point of CAFÉ and GHG standards is to fill in the gap between the consumers' value of fuel savings and the value to society. So, the standards should be targeted towards society's values, not the customers.
    - The equation for "Cost Effectiveness – Manufacturer" equation does not make sense. Unless a technology includes a fuel change, this equation will produce virtually identical results for all technologies. The CO2 summed in the denominator is directly proportional to fuel consumed summed in the numerator. The ratio should be virtually the same for all technologies, unless there is a fuel change. What is this equation trying to do?
    - Why is the fuel savings only summed over the payback period, while the CO2 savings are summed over the useful life? Why are they not the same?
- Target Function Type (column F) – I could not find a description of this field anywhere in the Model Description.
- Fleet type (column G) – The description in Rykowski's email response to Rubin should be added to the Model Description.
- Trading limit (column I) – The description in Rykowski's email response to Rubin should be added to the Model Description.

Economic parameters – The "CAFÉ fine" and "CO2 value increase rate" are fine. However, the other parameters may need modification:

- Discount rate – There is some thought that the CO2 discount rate should be different from the economic discount rate. I am not sure I agree with these arguments, but you may want to include flexibility to have a different discount rate for CO2 in the model.
- Payback period – As discussed, above, I am not sure this is needed. Any use of payback period should be explained and justified in the Model Description.
- CO2 fine – While the CAFE fine is used appropriately in the model, there is no consideration of a manufacturer paying CO2 fines instead of complying with CO2 standards. Of course, this is dependent on the compliance strategy adopted by EPA for its CO2 standards. But the model should have the flexibility to model CO2 fines; similar to how it handles CAFÉ fines.
- Gap – It is appropriate to adjust the test values for differences in real-world fuel consumption. However, the gap is not linear. As EPA demonstrated in their fuel economy label rulemaking, the gap increases as fuel consumption decreases. While the fuel economy

- I do not understand the value of "threshold cost" or how it is used. Lines 8-10 of page 8 state, "threshold technology cost (the cost at which manufacturers add technology to only enough vehicles to meet the standard as opposed to adding technology to all of a model line)". The detailed calculations later in the Model Description do not discuss how this is done. From a practical point of view, how does the model know whether or not the technology is needed to meet the standard when the technologies are feed into the model one at a time? More importantly, manufacturers have limited resources and the standards will drive technology development well beyond what a manufacturer would have done without them. Thus, why would a manufacturer add any technology to more vehicles than are required to meet the standard? Unless these concerns can be addressed in the Model Description, the "threshold cost" should be eliminated.
- Rebound effect – Line 38 on page 17 states that the rebound effect is an input in the "Economics" worksheet. However, it is not listed in the worksheet. In any case, the rebound effect is not handled appropriately in the model. The rebound effect is a sensitivity factor. But it is determined from a regression. Which means that the change in VMT is NOT a linear function of the change in fleet fuel consumption. Thus, the equation on lines 41-43 of page 17 is wrong. The actual relationship is logarithmic or exponential or something like that (I don't remember exactly what). The correct equation should be built into the model.
    - The rebound effect is also impacted by the price of fuel and household income. This should be added to the model (see medium- to long-term recommendations, below).

Minor suggestions:
- It appears that the "Cars A", "Cars B", "Cars C", and "Cars D" columns in the Target tab are intended to describe the footprint-based logistic curve. Does this mean that "Cars C" and Cars D" are also the Xmax and Xmin under the linear attribute option? If so, both descriptions should be in the column headings. Also, while the Model Description (page 6-7) includes a good explanation of the how the linear target and logistic curve work, it should also specifically state where the A, B, C, D, and X coefficients can be found in the spreadsheet.
- The economic parameters are discussed as part of the Scenario input file on page 8. Lines 12-13 also state that an example of the Scenario input file is in Appendix 3. However, Appendix 3 only includes the "Scenarios" tab and the "Target" tab. The "Economics" tab should also be added to Appendix 3.

Response: Mr. German is correct in that the TARF column in the Scenario file refers to the choice of one of the two available TARF equations. The model documentation has been clarified in this regard. The payback period is the period of time over which manufacturers believe that vehicle purchasers value fuel saving when purchasing a vehicle. If the user prefers to use lifetime fuel savings in the TARF calculation, the user can specify a payback period sufficiently long to cover the life of the vehicle

The point of including the fuel savings over a period of time in the TARF is to recognize that there is some increase in vehicle fuel economy which would neutralize the consumer's negative perception of an increase in vehicle price, thus nullifying any negative sales impact. This level of fuel economy increase is often estimated to be the fuel savings accruing over a specified number of years of vehicle operation which is usually less than the life of the vehicle. Thus, when either TARF is negative (i.e., the fuel savings exceed the cost of technology), this implies that the manufacturer could add the technology at its full cost and potentially increase vehicle sales (all other factors being held constant). Similarly, when either TARF is positive, this implies that if the manufacturer added the technology at its full cost, sales would decrease. We have modified the model documentation to better explain the rationale behind the TARF equations.

The fuel savings are typically summed only over a portion of the vehicle life because the timeframe considered by the vehicle purchaser is typically less than the life of the vehicle. (We have not included an estimate of the residual value of the added technology at the end of this time period, but will consider adding this in future model versions.) The lifetime CO2 emission reduction are included in the denominator since that represents the form of the GHG standard, particularly when car and truck trading is considered. For a single vehicle class, there is no need to include lifetime GHG reductions; the reduction in terms of g/mi would be sufficient. However, the lifetime GHG emission reduction provides the same ranking as the reduction in g/mi and also applies when car-truck trading is allowed. So including lifetime CO2 emissions in both cases allowed the same equation to be used in all cases.

Mr. German suggests that the point of GHG standards is to fill in the gap between the consumers' value of fuel savings and the value to society. That can be true, but this is accomplished primarily through the level of the GHG standard. The current TARFs are focused on the order in which manufacturers are likely to add technology to meet the standard. The TARF does not set the level of the standard. Manufacturers' primary goal is to maximize profits. OMEGA does not address all of the numerous factors which affect profit maximization. For a specified level of sales across a fixed model mix, profits are maximized by maximizing the profit per vehicle, or the difference between cost and price. The numerator of both TARFs attempt to represent this difference. Thus, the more negative the TARF, the greater the potential profit per vehicle and a manufacturer's desirability to add the technology.

The level of a GHG standard can be based on many factors, societal benefits being one of them. The benefit calculation worksheet is designed to facilitate the calculation of total societal costs and benefits and to assist in this evaluation.

The Cost Effectiveness – Manufacturer TARF is not constant for every technology. The Cost Effectiveness – Manufacturer TARF (ignoring the CAFE fee) is basically :

[Technology Cost less Fuel Savings over Payback Period] / Lifetime GHG Emission Reduction

Or

$$\frac{\text{Technology Cost}}{\text{Lifetime GHG Emission Reduction}} \quad \text{less} \quad \frac{\text{Fuel Savings over Payback Period}}{\text{Lifetime GHG Emission Reduction}}$$

Mr. German is correct that the ratio of fuel savings to GHG emission reduction will tend to be constant across technologies (at least those not aimed at reducing refrigerant leakage). However, the ratio of technology cost to lifetime GHG emission reduction will not be constant across technologies. The Cost Effectiveness – Manufacturer TARF can be presented as the difference between these two ratios, so it will differ markedly between technologies. Except for the inclusion of discounting in the calculation of the GHG emission reduction, Paul Lieby's comment in section xx of his comments presents an excellent description of the rationale behind the Cost Effectiveness – Manufacturer TARF.

We have clarified the description of all the model inputs in the model documentation.

We have also added a separate discount rate for the valuation of CO2 emissions.

As discussed above, including the payback period as an input allows the user to evaluate fuel savings over less than the life of the vehicle or over the entire life of the vehicle.

EPA has not typically allowed the payment of a fee in lieu of non-compliance for car and light truck emission standards. The typical fine for non-compliance is far in excess of the cost of technology and is retroactive in that it applies to past sales of vehicles which were found to violate the applicable emission standards. There is no provision for actively producing vehicles which do not meet applicable emission standards. Thus, we do not plan to add a separate CO2 fine to the Scenario file. The inclusion of the CAFÉ fee in the TARFs is to allow the user to use the OMEGA model under conditions which are similar to those possible with the Volpe Model. In model runs evaluating GHG emission standards, EPA would set this fee to zero.

Mr. German is correct that EPA's current MPG-based formulae for fuel economy labeling imply that the "gap" increases as fuel economy increases. The model currently assumes a constant gap with changing fuel economy. EPA will consider incorporating a more flexible definition of the gap into future versions of the model.

We have clarified the role of the threshold value in the model documentation. Basically, if the per vehicle cost of the last technology added by the model in order to enable compliance exceeds the threshold value, the model reduces the percentage of vehicle sales receiving that technology to just the degree needed to enable compliance. If modified the per vehicle cost of the last technology added by the model in order to enable compliance is below the threshold value, the model leaves the percentage of vehicle sales receiving that technology at the technology penetration cap for that technology. This flexibility was included in the model to reflect the different ways in which manufacturers apply various technologies. For example, when adding basic engine technology such as variable valve timing, the manufacturer would generally convert the entire production volume of a specific engine to this technology. Two different engines, one with the technology and one without, would not be maintained. However, with more extreme technologies, such as dieselization or hybridization, the manufacturer often maintains two versions, one with and one without these technologies. By setting the threshold in between the costs of these two examples, the model will reflect these two approaches to technology application on the part of a manufacturer.

If the threshold is set to zero, the model simply backs off from any predicted over-compliance.

The higher the threshold cost is set, the greater the degree of over-compliance which is accepted in a model run. Since the value of the threshold cost is set by the user, its inclusion only provides more flexibility.

The rebound effect has been evaluated in the literature in a number of different ways from a variety of datasets. It is typically defined as the percentage change in per vehicle VMT divided by the percentage change in the cost of driving one mile. Thus, it is a function of both fuel economy and fuel price. As the base cost per mile of driving in the various studies varies, there is some ambiguity in defining the rebound effect in this manner. Still, this is the norm used in the literature and we apply it accordingly. The benefit calculation worksheet determines the percentage in VMT per vehicle by multiplying the percentage change in fuel consumption per mile by the rebound effect.

The rebound effect is included in the benefits calculation file, in cell B3 on the Exclusive Inputs tab. It currently only applies to changes in fuel economy. However, future versions of the benefits calculation file will apply it to changes in fuel price, as well. As Mr. German notes, VMT per vehicle has also been observed to be increasing over time due to other factors, income probably one of them. An input for a secular increase in VMT per vehicle will also be included.

We have modified out descriptions of the values which are represented on the Target tab of the Scenario file to better describe their role in both the constrained logistic and segmented linear standard curves. We also have added a description of the values to be entered on the Economics tab of this file.

(I) Fuels Input File

The fuels file works fine for conventional gasoline and diesel. The Model Description does not address biofuels, but if needed the Fuel Input and the Upstream Emissions worksheets should be able to handle them.

Electricity is a special problem. A minor issue is that the Energy Density (column B), Mass Density (column C), and Carbon density (column D) are different than for liquid fuels. Liquid fuels are generally expressed in units per gallon. This doesn't work for electricity. The units for electricity in the Fuels Input sheet need to be defined. Also, I'm not sure what Mass Density would be for electricity – kg/kWh? And isn't carbon density meaningless, as the carbon is all upstream?

More importantly, the energy density and mass density for electricity are not fixed, but are dependent on battery construction. High-power Li-ion batteries for conventional hybrids may only have about 15 Wh/kg energy density, while high-energy batteries for PHEVs and EVs may have over 100 Wh/kg. In addition, start/stop systems and belt-alternator/starter systems may use lead-acid batteries and some conventional hybrids may continue to use NiMH batteries through the 2013-2015 timeframe. All will have different energy densities.

Minor suggestions:

- The Model Description, line 6 page 6, says, "There is a small subset of fuel information not included in this file". This is not accurate. Appendix 5 contains upstream emissions, which is an extremely important factor for fuels. This connection should be discussed in the Model Description.

- The appendices should be ordered to match the order they are discussed in the Model Description (i.e. the fuels Appendix should be before the Scenario appendix).

Response: Please see our response to xx comments on the inclusion of renewable fuels in the model. Mr. German is correct that the benefits calculation spreadsheet could be modified by the user to accommodate any different costs or emissions from the use of other fuels in vehicles which are certified on gasoline or diesel fuel.

The inputs for electricity in the Fuels file have been clarified in the model documentation. The energy density value for electricity does not apply to that of the battery type being used on the vehicle, so the variability in the latter value is not an issue. We have also modified our description of fuel-related inputs, incorporating Mr. German's comments, as well as other changes.

(J) Reference Data in Appendix 5

Downstream Criteria Pollutant Emissions:
The fields and the regressions as a function of age are appropriate. However, there is not enough flexibility to handle differences in fuel, future emission standards, and future fuel sulfur control:

- The model should be able to handle future reductions in emission control standards. This means that the model should allow the user to specify effective years for future emission standards and enter new regression coefficients.
- SO2 emissions are almost entirely a function of the sulfur level in the fuel. Thus, the model should also handle changes in fuel sulfur level. The model should allow the user to specify effective years for future sulfur reduction and the fuel sulfur level for both current and future fuels. If desired, the user would not have to enter regression coefficients for SO2, as there is a fixed relationship between fuel sulfur, fuel consumption, and SO2 emissions (much like CO2 to fuel consumption) that could be hard-coded in the model if the user specifies fuel sulfur levels.
- The regression coefficients will be different for gasoline, diesel, and electric vehicles. Average coefficients can be used for the current fleet, but these will not be appropriate if there is a substantial change in the future mix of diesels, PHEVs, or EVs. The model needs to allow input of different coefficients for diesel and gasoline – and possibly biofuels. Downstream emissions of electric operation should be zero and do not have to be input.
- It appears that the model does NOT calculate downstream pollutant emissions as part of the normal model accounting, only the additional emissions caused by the VMT rebound effect. This is not appropriate. If there is a switch to diesels or EVs, the downstream pollutant impact needs to be assessed by the model.

Upstream Emissions:

- The upstream emission inputs are fine for gasoline and diesel, although addition rows will likely be needed to handle biofuels and unconventional oils.
- It is not clear if the efficiency of battery recharging is included in electricity upstream

emissions. The model likely calculates only the mmBtu actually used by PHEVs and EVs during use. However, the mmBtu draw from the utility will be larger due to losses in the battery charger and in the battery chemical process. To ensure that the user handles this properly, it would be best to add an input somewhere for charging efficiency. Otherwise, the Model Description should explicitly state that the upstream grams/mmBtu for electricity must be incremented to include the losses in the charger and battery.

- Upstream emissions, both carbon and pollutant, for electricity will vary by region. While it is the responsibility of the user to input proper factors, there is a potential issue with stratification of PHEV and EV sales across the nation. Customers in urban areas are most likely to buy PHEVs and EVs will likely be limited primarily to a few, dense urban cores. It might be useful to have the Model Description briefly discuss the need for the user to input upstream values for electricity that are consistent with utility emissions in the urban areas most likely to purchase PHEVs and EVs.

Vehicle Age Data and historical data on average CO2 emissions and new vehicle sales:
These fields and inputs are fine.

Response: We agree with Mr. German's comments about the inability to reflect step changes in the downstream emission equations. Future versions of the benefits calculation file will specify downstream emissions by model year and age. Future versions will also include distinct emission estimates for vehicles operating on different fuels, such as gasoline, diesel fuel and electric vehicles. These estimates will apply to both base levels of VMT and rebound-related VMT.

Regarding upstream emissions, we agree with Mr. German that the inclusion of an efficiency value for battery changing (and electricity distribution) should be included so that the user can input upstream emission estimates based on kw-hr of power generation at the power plant. Changing the upstream emission calculations to reflect regional differences would involve substantial changes throughout the benefit calculation worksheet, as regional vehicle sales, VMT per vehicle, etc. would likely also differ. We believe that such regionalization of the model should be performed by those knowledgeable of the particular region of interest. However, we agree with Mr. German that the emissions input to the spreadsheet should reflect the emissions from the incremental increase or decrease in the production of that fuel and not the average emissions over the entire production of that fuel. We will modify the model documentation to reflect this point.

(K) Other Reference Data

Externalities related to crude oil use:
The externalities in the Externalities worksheet of the Benefits Calculation are only listed for imported oil. This is appropriate for military costs for protecting oil supplies, but it is not for the economic impact of periodic price shocks (and possibly for monopsony effects as well). Oil is a global commodity. Any reduction in oil use, either domestic or imported, will help reduce the economic impact of periodic price shocks.

Rebound effects:

The discussion of the rebound effects on lines 10-19 of page 3 and on pages 20-21 both imply that rebound effects are NOT considered in assessing the societal benefits from reduced crude oil use and GHG emission reductions. However, I would assume that these benefits are based upon total fuel consumption, which includes the additional VMT from the rebound effect. If my assumption is not accurate, then the social benefits associated with reduced crude oil use and the value of GHG emission reductions must be revised to include the rebound effect. If the benefits do include the additional VMT from the rebound effect, this should be clarified in the discussion on both page 3 and page 20.

Response: We have removed the word Imports from the title of the Oil Externality Section of the benefits calculation file. These externalities were applied to all reductions in crude oil use, not just to reduced imports. To the degree that an externality only applies to imported oil, the user should decrease the value of the externality by the ratio of the expected reduction in imported oil to the expected reduction in total oil use.

We have corrected the discussion of rebound effect in the model documentation. The reductions in crude oil use and GHG emissions always included the rebound effect.

<u>Recommendations for Improved Model Functionality – beyond "future work":</u>

(L) Recommendations for Short-Term Functionality

The functionality of the model is good. My only recommendations are those already described above, for improved handling of leadtime (section C), ability to handle multi-path technology inputs, (section D), and ability to calculate "maximum net social benefits" (section E).

Response: None required.

(L) Important Medium-Term and Long-Term Recommendations

1) By far the most important improvement is to use budgets for capitol expenditures to assess leadtime. The need for this and suggestions on how to implement it were discussed in section (C), above.

2) The rebound effect is impacted by both the price of fuel and household income. These should be added to the model. The work has already been done by Small and vanDender. Their equations should be added to the model, along with the necessary user input fields for future household income. An option to skip the fuel and income effects can be maintained, but it is important that the model be capable of properly calculating rebound effects.

- The time value of congestion and vehicle refueling are also related to household income. While this is of lesser importance than the rebound effect, it should be relatively easy to add household income effects to the value of congestion and vehicle refueling in conjunction with adding household income to the VMT rebound effect.

Response: We have added a secular growth rate to the calculation of VMT per vehicle to represent the impact of real income and other factors which have been increasing total VMT over time beyond growth in the vehicle pool. At the present time, the rebound is still assumed to constant over time. We are aware of the Small and vanDender study which has found that the rebound effect appears to be decreasing over time. Fortunately, this is not a factor for analyses which just evaluate one or two redesign cycles. Longer term analyses face even greater uncertainties with VMT per vehicle and other factors. Still, we will consider modifying the benefits calculation file to accommodate a changing rebound rate with time.

(M) Less Important Long-Term Suggestions

3) Inclusion of the city and highway fuel economy/CO2 values may help with assessing market penetration caps, although this can be done externally. Also, separate city and highway values could help calculate an appropriate in-use fuel economy/CO2 "gap" for different technologies with different city/highway fuel economy ratios. Separate city and highway numbers might also be useful for other purposes. EPA should consider adding these to the model.

Response: It is not clear how tracking or regulating city and highway CO2 emissions separately would address issues which Mr. German has raised related to the technology penetration caps.

Regarding the gap between onroad and certification CO2 emissions or fuel economy, this gap can theoretically vary between city and highway driving. However, as EPA described in its supporting analysis to its 5-cycle fuel economy labeling rule, data on onroad fuel economy during city and highway driving is very scarce. Thus, assessing the distinct impact of technology on certification and onroad CO2 emissions during city and highway driving would have to be based on vehicle simulation modeling. Such models are commonly used to simulate vehicle operation over the EPA city and highway certification cycles at the test temperature of 75 F. However, few vehicles, and even fewer control technologies have been modeled over other driving cycles, such as the US06 high speed, aggressive driving test, the SC03 air conditioning test and the standard test cycles at low ambient temperatures. Thus, at the present time, there are insufficient data available to determine how various technologies would affect the "gap" over city and highway driving. Until such information becomes available, the value of expanding the model to include separate city and highway estimates of the gap would be of limited use. If such information becomes available, it would be a simple task to add such capability to the benefits calculation worksheet. Incorporating this into the core model would be a more significant task. The primary requirements would be to input onroad city and highway gaps for each technology. It would probably also require the use of separate effectiveness estimates for city and highway emissions for each technology. Compliance would still be determined based on combined city/highway emissions.

4) Value of time required to refuel vehicles:
The model handles this appropriately for liquid-fuel vehicles. However, PHEVs and EVs will add refueling time, both because of the need to plug in and, in the case of EVs, the shorter range. This should be added to the model. Ideally, it should also be added to the TARF assessment.

Response: Mr. German raises important points about PHEVs and EVs which need to be factored into the consideration of their expanded use in the future. At present, the only consumer benefit which OMEGA includes in either of the TARFs is the value of fuel savings. Other effects, such as a change in refueling time, are included in the calculation of societal benefits, but not the TARF. There are other attributes of PHEV and EV use which will also affect their value to the consumer. For example, the reduced range of EVs relative to conventional vehicles is a serious limitation for some consumers, but not for others. Some PHEVs are designed to run most efficiently on battery power and only resort to liquid fuel use when the battery has run out of useful energy. Other PHEVs operate best on a mix of electricity and liquid fuel. However, even these PHEVs eventually run out of stored battery power and convert to operation solely on liquid fuel. Their operational cost varies depending on daily driving distance, as well as climate. Unfortunately, there are significant uncertainties surrounding the details of how people drive and how they would drive if they owned a PHEV or EV. Thus, limitations exist today regarding both the appropriate inputs and modeling capability before these issues can be fully represented in an automatic fashion in a model run. In the near term, users modeling GHG standards which require or reflect significant levels of PHEV and EV penetration should take care to limit their penetration to portions of the driving public whose driving patterns are compatible with the range of these vehicles. Or, if the penetration of PHEVs is such that they would be driven significant distances on all liquid fuel power, that their CO2 efficiencies reflect such use.

B. Comments by. Paul Leiby

Thank you for the opportunity to review this model and its documentation. This is an important project, and the EPA team has made great progress in developing a coherent, informative, and very usable system. I understand that this is a work in progress and, regrettably, many comments can only refer to its current (May 1, 2009) state. Also most of the comments are in the form of what might be changed or improved, with the hope that these might be most useful. I would like to say at the outset that everything achieved so far is well worthwhile, and some features are quite marvelous. Please also interpret statements below of the form "the model does/does not" as meaning "as far as I could discern so far, it seems like the model does/does not." Statements like "the model/documentation should" really mean "Perhaps it would be helpful if the model/documentation were adjusted to…." In sum, this work is to be applauded and I look forward to its next iteration. Comments are offered in order of the questions posed, and in structured bullet form.

Questions to address:

1) **Comments on: The overall approach to the specified modeling purpose and the particular methodologies chosen to achieve that purpose;**
   - This model fills an important need for an independent capability to assess how manufacturers might respond to GHG emission regulations on light-duty vehicles.
   - There is much to recommend this model, which grapples with some key challenges of assessing how progress toward tighter fuel use or GHG emissions standards can be achieved through incremental vehicle technological change, and at what cost.
   - The essential approach of this model is consistent with others in a similar vein, with the most notable predecessor being the NHTSA "Volpe Model." It describes the set of technological possibilities for improving vehicle fuel economy, or reducing GHG emissions, characterizing for each technology the cost and incremental change in

emissions and fuel use. It determines a sequence of introduction for fuel-economy (or fuel switching) technologies necessary to meet a fleet-average CO2 emission constraint for each manufacturer. However it differs from some other approaches in significant ways:

    - 1. The sequence of discrete technologies that can be used for any single "Vehicle Type" is *exogenously* specified by the user. Those fixed technology successions *t*, *t*+1 … for each vehicle type *v* ,essentially define a vehicle-type-specific supply (marginal cost) curve for emissions reduction. The model determines the sequence in vehicle types each separately progress in an orderly fashion down their emissions reduction technology curve.
    - 2. The model makes vehicle technology redesign decisions not annually, but for each vehicle "design cycle," which is typically specified as a fixed number of years.
    - 3. The algorithm does not do a simultaneous choice of the set of technologies that minimize vehicle net costs such that the GHG emission standard is met. Rather it iteratively "dispatches" discrete new technologies by choosing which vehicle is to progress next by one more step through its sequence of technologies. It repeats this dispatching over vehicle types until the fleet average GHG emission standard is finally met. The choice of which vehicle type is to receive more advanced technology is based on one of two figures of merit, called "TARFs."

- It is wisely stated that effective model design hinges on a careful definition of its purpose or purposes, and an acknowledgement of its bounds and limitations. The documentation could be much strengthened in this regard. Here is my impression of its suitability:
    - This model is currently most suited to estimating the incremental net technological cost of any single manufacturer achieving various GHG emission levels, specified as an average for that manufacturer's new-car fleet. It accounts for technology costs and lifetime fuel cost savings in its dispatching of technologies for each manufacturer's fleet. Other attributes and societal impacts may be monitored *ex post* (e.g. the extensive and somewhat disparate list on the top half of p. 3, including criteria pollutant emissions, noise, congestion, refueling time, etc.) but these are *not* considerations in the model's solution, i.e. in the core algorithm that sequences the application of vehicle technologies.
    - A compact way to describe the models approach is that, like the Volpe Model, its solution has two phases: "manufacturer compliance simulation" (with cost-based technology choice) and "effects estimation" (based on a diverse set of *ex post* calculations).
    - The model does *not* project vehicle sales, or sales mix, or aspects of vehicle design and vehicle appeal to consumers, apart from altered lifetime vehicle capital and fuel use costs. This is not mentioned as a flaw, but as an important design choice that should be stated. Large changes in fuel economy and GHG emissions could have important indirect impacts on the design and appeal of the vehicle, particularly if tradeoffs are made in the areas of vehicle size, weight, performance, range, and, for alternative fuels, fuel availability and convenience.
    - The model treats each manufacturer's regulatory attainment problem independently, and is not currently designed to model "flexible" emission

standards that allow permit trading among manufacturers, permit banking or borrowing, or economy-wide GHG trading systems.

Response: Dr. Leiby states that the current model is not able to reflect credit trading between manufacturers when determining compliance, or banking of credits. We agree that the model does not allow these types of credit programs to be modeled explicitly. However, completely flexible credit trading between manufacturers can be simulated by labeling all vehicles as being produced by a single manufacturer. The model then estimates the costs and benefits of bringing the entire industry's new vehicle sales into compliance. Also, the flexibility to bank and borrow credits within a redesign cycle is implicitly assumed by the model. OMEGA assumes that a manufacturer's entire fleet of vehicles can be redesigned within one redesign cycle. (Actually, less than 100% of vehicle sales can be assumed to be redesigned through the technology penetration caps included in the Technology file.) However, rarely will a manufacturer redesign exactly 20% of its vehicle sales in each of five straight model years. The base emissions and emission reductions of the vehicles being redesigned will vary. Thus, the banking and borrowing of credits will be needed to enable compliance with standards in the intermediate years of a redesign cycle using the technology projected for the final year of the cycle, assuming that the intermediate standards require gradual improvement each year.

- Suitability of method
    - To some extent the discussion of the manifold ancillary benefits and costs can be a distraction, since a coherent and complete framework for their endogenous analysis is currently outside the scope of this model. I suggest that the model developers may wish to stay focused first on clearly and rigorously modeling the fuel-economy technology choice and cost-effectiveness considerations, for various GHG emission levels. Where possible, one reasonable design approach might be to assume that other vehicle attributes are essentially held relatively constant, for each vehicle size and type.
    - Overall, the model documentation suggests that model developers may be hopeful of doing too much soon, with many (over 10) stated intentions for future extensions. Better and sounder results may follow from strategically limiting the model scope, carefully testing the model (in full, with real datasets), and then selectively adding features over time.
    - One feature of this model approach is its comparative analytical simplicity but heavy reliance on specialized data inputs (discussed further in Item 2 below). This should be viewed as a model strength: its contribution need not rely on analytical sophistication, but also on the coherent application of good quality, widely reviewed data.

Response: The current model does not allow the vehicle sales mix to change as a function of technology. When applying the model itself, EPA has developed effectiveness and cost estimates for the various technologies which hold vehicle attributes such as size and performance constant. Vehicle weight may change, as for example with dieselization or hybridization. However, in these cases, the effectiveness of the technology should reflect the change in weight.

- Two major methodological points:
    - In any model, particularly any model of markets with social externalities and government intervention, it is essential to be very explicit about *whose* behavior and objectives are being modeled. Otherwise there is danger that nobody is really being described, or that we might impute particular knowledge and incentives to market actors who actually have neither. Naturally a model can be both normative, saying what should be done optimally, or descriptive, saying what we think will be done by some actors in certain circumstances even if it is not clearly optimal. And it can apply to what would or should best be done for different agents: vehicle consumers, manufacturers, or the government/society as a whole. I am a little unclear about whose behavior is being modeled in the succession of technology decisions made. It appears the intent is to model market behavior of competitive vehicle manufacturers facing cost-minimizing consumers and a firm-wide emission constraint. But the objective of such a firm is not explicitly stated, and the solution rules are not clearly mapped to that objective.
        - In this matter it seems that the Volpe Model has set a good example by succinctly and specifically stating up-front whose behavior is being modeled: "The system first estimates how manufacturers might respond to a given CAFE scenario, and from that the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities." [P. 1, http://www.nhtsa.gov/staticfiles/DOT/NHTSA/Traffic%20Injury%20Control/Articles/Associated%20Files/811112.pdf]
        - Would a similar description not also apply to the EPA GHG model?
    - Given this idea of modeling the behavior of particular actors, e.g. manufacturers, in mind, the objectives of the actors should be reflected in the solution method or optimization condition. Bearing this in mind, there are some concerns with each of the two TARFs proposed as technology-dispatching figures of merit.
        - The "EffectiveCost" TARF is essentially the cost of each technology net of its discounted lifetime fuel savings (omitting the problematic "FEE" component, which seems mis-specified). Arguably, minimizing this would be a correct objective of new-vehicle consumers who discount fuel savings in the same way and given no change in non-cost vehicle attributes. This could also be the objective of competitive firms acting on behalf of prospective consumers. In a mixed integer program these costs would be minimized *subject to* meeting the emission standard, and the algorithm would choose the least cost combination of technologies. The possible problem is that the EPA GHG Model algorithm sequentially dispatches new technologies in order of EffectiveCost, but without regard to their effectiveness in reducing GHGs. Some technologies with low net-cost could do little for GHG reduction. In the limit a low EffectiveCost technology, say using a high-GHG alternative fuel could even increase GHGs (FFVs with coal-fired corn-ethanol?). Regardless, there is no assurance that the suite of technologies finally assembled to reach the

GHG standard in this way would be the low-cost suite. The authors may wish to consider when they recommend that the first, EffectiveCost TARF, is appropriate.

  - The "CostEff" TARF on the other hand leads to an algorithm sensitive to both cost and cost-effectiveness for GHG reductions. Such a cost-benefit ratio can lead to optimal selection rules for packing (knapsack or budget) problems. But some confusing terms are included in the TARF, most notably the non-standard way in which VMT is discounted for the purposes of this TARF (See equation top of page 11, line 1). The inclusion of "IR" ("the annual increase in the value of CO2") in the discount factor is done without explanation or justification. While the term IR is never really defined (is it meant to be the growth rate in GHG damages, abatement cost, or a CO2 tax?). It inclusion seems to conflate considerations of social benefit (value of GHG avoidance over time with cost (of technologies). The vehicle manufacturer's cost of GHG avoidance is already embodied in the TARF numerator. The denominator should perhaps only reflect the quantity of GHGs avoided. As currently written, this CostEff TARF would not seem to be a consideration for vehicle manufacturers whose objective is to produce a new-car fleet meeting consumer needs and a GHG emission standard at least cost. What objective was intended with this hybrid aspect of the TARF?

- There are other important methodological points to raise, that are discussed below in Section 3 on conceptual algorithms.
- At this point, please allow an extended comment on the model documentation. Clearly it is in draft form only, and there would be much benefit from improving and clarifying it. This is not simply a matter of fastidiousness, but is an essential aspect of making the intellectual case for this model. As it stands, understanding the model was much more work than need be. Some specific suggestions are:
  - Restructure the presentation, perhaps following the pattern of a journal article. (E.g., begin with stated purpose and background. Place this model in the constellation of related models and indicate what is different and why. Describe approach, data sources. Sample results.)
  - Bringing description of the "Core Program" and what the model does toward the front.
  - Clarify and condense the model description. Classically, this would involve:
    - State model objective (typically stating what is maximized, minimized, or what final solution condition is sought)
    - State model constraints
    - State and discriminate between principle decision variables, exogenous inputs, parameters, and internally calculated results. (This is not done in the variable list of Appendix 6, which also is incomplete. It omits AIE, PF, CAP, TCO2, IncrementalCost,

TechCost, TARF, VMT, SurvivalFraction, AnnualMilesDriven, Leakrate, RefLeakage).

- State the solution algorithm and termination condition

- Rigorous use of notation. Currently, for example, the subscript *i* usually refers to "year" (eqns on page 10 and 11) but sometimes indexes technology (eqns at line 10 on p.12).
- Use consistent variable names. For example, on pp. 16 and 17, it appears that the same variable is called "ModelSales", "Sales,", and "Annual Sales."
- Clarify subscripts and carefully apply them. The principle subscripts that seem to apply are:
  - t: technology number in sequence for each vehicle type
  - i: actually vehicle *age,* which is to be distinguished from year
  - y: year (which indexes, eg. fuel prices)
  - v: vehicle type
  - m: manufacturer
  - For example, equation at bottom of p. 12 is missing subscripts on AIE and RIE (presumably *t),* while GWP in that equation is indexed by technology t yet elsewhere (e.g. middle of page 11) it is not.
- Carefully state units. Physical equations cannot be fully understood without a statement of the dimensions. For example, the equation in the middle of page 11 can be more readily understood if "Leakrate" is known to be in [g-GHG/yr], not [g-GHG/mi].

o Overall, the authors might wish to look at the documentation of the NHTSA Volpe model as a helpful template.
  - That documentation is actually reasonably compact (35 pp plus an extended guide to operation).
  - It gives an excellent, succinct prose summary of what the model does in the first 3 pages (1-3), and much of the wording might be applicable to the EPA model.
  - It clearly states what is being modeled:
  - There is a flow chart and a technology sequencing flow chart
  - Equations are then presented in orderly manner with consistent notation and subscripting.

Response: The TARFs are intended to reflect the decision making of a manufacturer. Since the manufacturer must satisfy its customers and regulatory mandates, a manufacturer's decision making processes will reflect these needs, as well. More explicitly, the technology cost is the full cost of that technology at the consumer level, including research and development costs, amortization of capital investment, etc. This cost is generally the same cost as EPA estimates in its regulatory support analyses when estimating the cost of new standards. This cost is not necessarily the increment in price that the manufacturer would charge for that technology, since price is a function of many factors which can change fairly quickly depending on market conditions. The fuel savings are those assumed to be valued by the customer, so they are based on fuel prices including taxes and reflect the timeframe which a customer might consider when purchasing a vehicle. The residual value of the added technology is not currently reflected in either TARF, but could be added in the future. The rationale behind the TARFs will be clarified in the model documentation to reflect these points.

The Effective Cost TARF was included in the OMEGA model since it is the equivalent of the technology ranking process used in NHTSA's Volpe Model. It allows a user to match this aspect of the Volpe Model when modeling equivalent standards using both models, if this is desired. We agree with Dr. Leiby that this TARF does not factor in the degree to which adding a technology will move a manufacturer's fleet toward the regulatory target. The CostEff TARF was designed to incorporate this factor.

We agree with Dr. Leiby that the inclusion of discounted GHG emission reductions in the denominator of the CostEff TARF is not consistent with the manufacturer focus of the numerator of this TARF. Future versions of the model will remove the discounting. The use of lifetime emission reduction in the denominator of this TARF will then be consistent with the standards contained in the EPA vehicle GHG proposal, where car-truck trading is based on lifetime emissions of each type of vehicle.

The discounting of CO2 emissions is more appropriate for a TARF whose focus is societal effectiveness. Thus, we plan to add a third TARF which is similar to the CostEff TARF and which retains the discounting of GHG emission reductions in the denominator. Newer versions of the model allow for an increase in the real value of CO2 emissions per annum. Thus, we believe that the discount rate used in this new TARF should reflect the difference between the broad economic discount rate specified and the rate of increase in the value of CO2 emissions. When this TARF is used, it will be most appropriate to value fuel savings over the life of the vehicle and this will be suggested in the model documentation.

We have significantly revised the model documentation, including the consideration of all of Dr. Leiby's comments above.

3) **Comments on: The appropriateness and completeness of the contents of the sample input files. (EPA staff are not seeking comment on the particular values of the contents of the input files, which are samples only.)**

- First, an overall point on data. While the instructions urge reviewers to not consider the particular values of sample data, it must be born in mind that models are essentially datasets, the equations which link the data, and the algorithms for achieving the solution of those equations. In this case the model equations (in the documentation) are reasonably straightforward, although the algorithm for their solution is somewhat opaque (not explicitly stated and embedded within a compiled module). Assuming a reliable solution algorithm (something hard to test in this review and with limited data), model quality will then depend strongly on the quality of model data. This is particularly worth mentioning because many of the data needed for this model are not readily available from established sources. The model calls for detailed, specialized, knowledge about vehicle technologies, their costs, incremental contributions and interactions, their availability over time and across vehicle types, *and* the data-providers must determine the sequence of technology application within each vehicle type. Ultimately, this dataset is likely to be the most valuable and significant component of this model. Particularly if it becomes publicly available, and serves as a standard. Thus the data issues should not be minimized.

- In all data input files, it would help minimize errors if units were specified. Kilograms or grams, etc. The "Fuel" datasheet does not indicate the unit for price ($/gge, in nominal $?. What are the units for electricity?)
- The "Data Validation" capability and error report is a very useful feature. Ultimately the modelers may wish to error check almost all inputs for acceptable range, if that is not already done.

Response: EPA will publish a complete set of input files which it used in its OMEGA model runs in support of its recent proposal to regulate GHG emissions from cars and light trucks. These input files were developed from publically available data explicitly to allow their full and complete release to the public for review, comment and use.

We agree that better descriptions of the input data are needed. Incorporating these into the input file headings themselves involves changes to the core model. In the near term, we have included detailed descriptions of each type of input value in the model documentation for easy reference by the user.

The validation criteria included in each of the model's input files generally prevent the inclusion of clearly inappropriate values (e.g., negative values where only positive values make sense). The current criteria apply such restrictions to nearly all the input fields other than labels. In addition, the criteria can be modified by the user to incorporate additional or more restrictive criteria which are deemed helpful. This flexibility will be described in more detail in the model documentation.

2a) The elements of the Market input file, Appendix 1, which characterize the vehicle fleet;

- This file describes vehicle sales by manufacturer and vehicle type, and provides the attributes of those vehicle types.
- No specific comments at this time.

2b) The elements of the Technology input file, in Appendix 2, that constrain the application of technology;

- As discussed above, this could be said to be the heart of the model. It requires both detailed technological knowledge *and* considerable judgment about the sequence, timing and impact of each technology.
    - It may be worth a special task just considering what range of technology attributes can reasonably be specified, even by a technology or industry expert.
    - The possible strong-sensitivity to data specification may also call for formal method of risk or sensitivity analysis, given limits on the ability to refine the data.
- How are technology interdependencies across vehicle types represented? Given outsourcing and the cost reductions from component sharing, would the application of a technology for one vehicle type make it more likely to be applied to another vehicle type? I could not discern how such considerations are represented in the data, and reflected in the solution algorithm, if they are.
- The data challenge is even greater if the stated goal of representing technological learning is pursued. While ultimately technological progress (through autonomous gains from R&D, scale economies and learning-by-doing) should probably be acknowledged in a later model version, benchmarking that progress is never easy. Moreover, technological learning and progress will be a function not of choices for each Vehicle Type (as the spreadsheet organizations suggests), but of industry-wide developments across vehicle types and manufacturers.
    - In our models on new vehicle technology introduction, we have found it useful to distinguish between 3 types of technological progress: autonomous progress over time due to R&D; progress or cost reduction due to production scale (units produced per plant); and progress from Learning By Doing (LBD). All three of these play a role, but the proper benchmarking of each is quite challenging. I agree learning should be approached, but cautiously because its specification and parameterization can have such a pronounced effect on model results.
- Spot-checking these entries, I did not see any items associated with changing vehicle size and weight. This may be a design choice rather than happenstance for the sample data: technologies that substantially change the vehicle design and hedonic attributes for the consumer would call for a more rigorous assessment of net-value to the consumer, and a potential re-statement of objective (TARF sequencing rule).

Response: Cost reductions due to learning are not yet incorporated into the model. Thus, there are currently no connections between the costs of technologies applied to different vehicle types. When learning is added to the model, the user will likely be able to specify whether this learning is based on the number of vehicles which receive this technology by manufacturer or industry-wide. The latter approach will provide a connection between technology costs across vehicle types. We will consider the suggestions provided by Dr. Leiby as we develop the learning related algorithms for future versions of the model. Prior to the inclusion of learning, the user can input technology costs which reflect the anticipated use of a technology across vehicle types and manufacturers. These projections can be compared to the results of model runs and adjusted accordingly.

As mentioned above, the current model does not allow the vehicle sales mix to change as a function of technology. Holding vehicle attributes such as size and performance constant when applying technologies simplifies the treatment of hedonics. A user could include a technology which included a change in vehicle size or other attribute. In this case, the user should adjust the cost of the technology to reflect the anticipated change in the vehicle's value from a consumer perspective. However, the limitation of this approach is that it would not adjust the applicable footprint-based GHG standard if the reduction in vehicle size would actually change the vehicle's footprint. There is currently no mechanism included in the OMEGA model for changing a vehicle's footprint from its base value. The model would also not reflect any change in sales which might accompany such a change in vehicle size or other attribute. The user could project a change in vehicle size in future redesign cycles and estimate the technology and cost necessary to bring this adjusted fleet into compliance. The cost of the change in vehicle size could then be added outside of the model. EPA does not have any plans in the near term to incorporate a change in vehicle size and resultant changes in consumer choice into OMEGA in the near future. One researcher, David Greene, recently concluded that, given time for vehicle redesign, on the order of 95% of the fuel economy improvement induced by feebates is likely to be achieved through the application of improved technology rather than a shift in vehicle sales patterns.[1] Thus, ignoring changes in the fleet mix may not be a substantial limitation.

2c) Scenario input file, definition of the standard and economic conditions (Appendix 3)

2d) The elements of the Fuels input file, Appendix 4

- This list does not yet reflect biofuels or renewable fuels, which are a growing consideration, in no small part due to recent law and EPA RFSs.
- Some provision may be needed for the variable energy and GHG content of gasoline, as the ethanol content varies over time.
- Provision may also be needed for E85, and the uncertain fraction of E85 use by FFVs.
- The net fuel economy and emissions by PHEVs remains an area of continued study. EPA is well aware that fuel use by fuel type and resulting emissions depend on PHEV design (AER), consumer use patterns, time of recharging, and the fuel used for regional grid generation. Nonetheless, some simplified representation of the alternative PHEV designs will be needed soon. I was unable to ascertain what progress EPA has made in this area.

2e) The reference data contained in Appendix 5. (Implied flexibilities and constraints of the model)

- No specific comments

Response: The current version of OMEGA focuses on gasoline, diesel fuel and electricity because the vast majority of current vehicle sales are certified on these fuels. Very few dedicated alternative fueled vehicles are sold and flex fuel vehicles are certified on either

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[1] "Feebates, footprints and highway safety," Transportation Research Part D 14 (2009): pp. 375-384.

gasoline or diesel fuel and numerical adjustments made to their fuel economy or emissions to reflect incentivizing regulatory credits. Future versions of the model will allow the user to include an anticipated level of FFV credits by manufacturer and by redesign cycle which will effectively adjust the required level of fuel economy or GHG emission control.

Current legislation and enabling EPA regulations encourage the use of renewable fuels. However, to date, these requirements are not integrated with the regulations governing vehicle fuel economy, nor the standards contained in the EPA vehicle GHG proposal. Thus, the primary place which they intersect with the OMEGA model is in the calculation of benefits. As this is done in a spreadsheet, the user could easily modify the calculations to reflect an anticipated use of renewable fuels over time. EPA may develop a standard version of the benefits calculation spreadsheet in the future which facilitates this use. However, as suggested by Dr. Leiby above, this is not the first priority at this time.

We agree that gasoline quality changes over time, but these changes are relatively small. We will consider including a varying quality for gasoline and diesel fuel over time in the benefits calculation spreadsheet as improvements are made to it.

At present, the model assumes that PHEVs will be driven like any other vehicle. Given the difference in the economics of their use when driving over short and long distances, it is possible that PHEVs will be driven differently than other vehicles. Unless this is reflected in GHG regulations, however, the core model should treat PHEVs like any other vehicle. They could be treated differently in the benefits calculation spreadsheet. This difference could be reflected by the user using information already included in the spreadsheet (i.e., emission and sales per vehicle after the application of technology). EPA will consider incorporating the potential for such a difference once better estimates of how the operation of PHEVs might differ from conventional vehicles becomes available.

3) The accuracy and appropriateness of the model's conceptual algorithms and equations for technology application and calculation of compliance;

- Equations for technology application:
    - The sequence of technology application, and timing and extent of application, for each vehicle type, is exogenous.
    - Modelers acknowledge that "This approach puts some onus on the user to develop a reasonable sequence of technologies." As noted, the onus may in fact be quite substantial. Therefore, it is helpful that the model "produces information which helps the user determine when a particular technology or bundle of technologies might be 'out of order.'" [p. 7] Any such capability to assist the user with stage-1 exogenous technology sequencing for individual vehicle types is worthy of further development and greater prominence in the documentation and model.
    - The Volpe model seems to currently offer more facility for specifying the structured sequences introduction of technologies or groups of technologies. The EPA GHG Modelers may also wish to develop some tools that make it easier for users to group and sequence technologies, perhaps even with logical diagrams that

map to or from the Technology.xls dataset. This would help experts represent their best judgement about technologies can or would be applied.

- While this model allows for substantial technological detail, there will always arise further, potentially important, complexities. In this review I could not determined the degree to which the model can account for cross-vehicle-type, or cross-manufacturer, interactions in the selection and sequencing of technologies. For example, various forms of hybridization are mentioned as technology options. We already see that one manufacturer, Toyota, develops a hybridization technology for one vehicle it quickly spread to other vehicles from that manufacturer, and that same technology is also sourced to other manufacturers (Nissan). Can this be represented in some way?
- P. 17 says: "Finally, the model determines the order in which technology packages are added to vehicles. The model first compares the TARFs corresponding to technology package 1 on all of the different vehicle types in the fleet and chooses the combination with the lowest TARF."
    - What does "combination" mean here? I understand it to mean the model chooses a combination (pair) of particular vehicle *v* and technology step *t* (advancing from *t*-1 to *t*).
- Technical points on the TARF-based rules for technology application (Equations p. 14):
    - As mentioned, net cost ("EffCost") alone would not seem to be adequate for sequencing GHG-reduction technologies
    - The inclusion of a FEE for non-compliance has some issues (admittedly, the Volpe Model does something like this as well, but the justification is not compelling):
        - It embeds the cost of non-compliance in an algorithm that ends only with compliance. Hence the fee should ultimately be zero. Is the intent here to employ some sort of penalty-function based algorithm for constrained optimization?
        - "Non-compliance" is a manufacturer-wide condition, and cannot be associated with a specific individual vehicle or technology (Note: I believe the TARF measures should be subscripted with m,v, and t, to highlight that they are specific at that level).
        - As written, the FEE is applied to the change in fuel economy (mi/gge, MPG) for that particular technology step. This is not a measure of non-compliance, and its essential effect is to exaggerate the relative importance of fuel savings. Note that the fuel-savings term is proportional to (FC_{t-1} - FC_t) while the Fee term is proportional to ($1/FC_t – 1/FC_{t-1}$), essentially a monotonic non-linear transformation of fuel-savings. So even though there will be compliance an no fee, the effect will be to boost the weighting of fuel savings in a non-linear way.
    - A maintained assumption is that fuel economy technology will not alter sales volume or share. But does or could vehicle sales volume influence the choice of technology introduction? I only noted "Sales" being referenced in the post-processing calculations, and it is used in the tests for

compliance. But sales is not a consideration in the TARF for a vehicle-technology pair, nor in the terms leading up to it, so the technology sequencing is based entirely on per-vehicle cost analysis. This approach is taken in other models and is not unreasonable. But if technology learning or scale economies matter, for example, the choice of which vehicle to apply the next technology to could be related to the sales volume of particular vehicle-types.

    - As mentioned, the non-standard adjustment of VMT discounting in the denominator of the CostEff TARF should either be eliminated or more explicitly and rigorously motivated. As it stands it seems to either mix social benefits of GHG reduction with the manufacturer's objective of meeting the emission standard.

- On p. 13, the equation for Fuel Savings (FS) seems to be in error. Fuel price (FP) is divided by *i,* which denotes the age of the vehicle (year after its production). Is this simply a typographical error and a discount factor was intended (e.g. $(1+DR)^i$?)
    - In all cases where the lifetime value of fuel savings in considered, the challenge is to be clear about whose valuation of fuel savings is being calculated. It is widely observed that consumers, when making new vehicle purchase, may "undervalue" fuel savings either with a higher discount rate or a short planning period than actual vehicle operating life. I understand that these issues are probably behind the formulation used here, but it would help to be more explicit. If manufacturer decisions are being modeled, the relevant question seems to be "How many years of discounted fuel savings would the manufacturer assume it will be able to recover from the consumer through the vehicle sale price?"

With respect to the flexibility afforded by the Volpe Model, the Volpe Model separates technologies by the aspect of the vehicle being modified (e.g., engine, transmission, accessories, vehicle (aerodynamic drag), etc.). A path is specified for the application of technology within each group. These paths are embedded in the model code and cannot be modified by the user. In contrast, with OMEGA, the user can modify the order in which technology is applied.

We agree with Dr. Leiby that the development of the technology steps is both integral to the model's operation and a challenging task. EPA will consider developing spreadsheet tools and procedures which will assist a user in developing such inputs. However, since modifying a vehicle is a complex engineering task, developing model inputs which reflect such changes will never be simple. EPA will publish its Technology input file which was used in its OMEGA modeling to support its recent proposal of GHG standards. The regulatory support documents to this proposal also describe how EPA developed these inputs. In general, the cost of the flexibility afforded by the approach taken in this area is greater responsibility with regard to the technological inputs to the model.

The OMEGA model applies technology to one vehicle at a time, but does so by evaluating the costs and benefits of technology applicable to a manufacturer's entire vehicle line. This is possible, since essentially every vehicle model is redesigned once during every redesign cycle.

This causes OMEGA to apply more consistent levels of technology to all of a manufacturer's vehicles. Thus, OMEGA would generally not predict the application of hybrid technology to one vehicle, while applying little or no more conventional technology to another vehicle. The exception would be if the TARF for the hybrid technology was less than that for the conventional technology, meaning that the former was generally more cost effective than the latter. Models evaluating compliance annually can sometimes apply very disparate levels of technology from one year to the next based on the number of vehicles which can receive major technological change in each year. Also, in our analyses in support of the EPA vehicle GHG proposal, EPA grouped vehicles by platform and engine size. This avoids applying one level of technology to the sedan configuration and another to the coupe configuration of a vehicle built on the same platform.

At the same time, OMEGA would predict that Toyota, to use Dr. Leiby's example, might hybridize the sales of the Camry up to the cap set for hybridization of this vehicle type and none of the Corolla sales. In reality, Toyota might choose to hybridize a portion of both vehicles. EPA does not believe that any model can predict the precise use of technology on every vehicle for a given fuel economy or GHG standard. Models such as OMEGA produce a reasonable estimate of the total application of various technologies and their overall cost. The user must interpret the results at this level and avoid putting too much confidence in the model's predictions for any specific vehicle.

Manufacturers can also introduce technologies for various reasons. Some technologies, such as the early hybrid models, were introduced for marketing purposes and to develop experience. Some technologies were developed for overseas markets and are sold in small numbers in the U.S. A model which uses economic efficiency as its primary tool for applying technology will not be able to capture these vagaries in technological application except by including them in the baseline fleet (i.e., as being outside of the impact of the GHG controls being evaluated). Incorporating manufacturer-based learning into the cost estimation will help somewhat, as this will lower the cost of technology for those companies which have already applied certain technologies in the past. However, again using Dr. Leiby's example, no regulatory model would predict that Toyota would introduce hybrids over a number of their vehicle lines, as the use of this technology was not driven by regulation.

On page 17 (of the model documentation), "combination" referred to a combination of vehicle and the next technology available to that vehicle. This has been clarified.

The CAFE compliance fee is included so that the user can match this aspect of the DOT Volpe Model if desired. As discussed in Section H of John German's comments, such a fee or fine is not applicable to an EPA GHG standard and would normally be set to zero by the user. We agree that the calculation of the impact of the CAFE fee was performed incorrectly in the version of the model which was reviewed. This has been corrected.

Regarding the potential impact of sales volume on the TARF, this will need to be considered when EPA incorporates learning into the model. Some projection of the sales volume over which a technology might be applied will likely have to be made when calculating the TARFs. Then, at the end of the model run, the technology cost can be adjusted to reflect the actual use of each technology. If the TARF is based on the level of technology use up to that point in the model run, the cost of the same technology could decrease (for TARF calculation purposes) during a run when in fact it is the same. Manufacturers can generally be assumed to be forward looking when deciding to apply technology, considering the sales volume which will receive the technology over at least a full redesign cycle of all of their vehicles. Of course, if the learning is occurring at the supplier level, costs will decrease based on total industry sales, which will not bear any semblance to the level of application occurring to the first manufacturer's vehicles. In this case, the model output could even be dependent on the order in which the model evaluated the various manufacturers, which is not desirable. Thus, it will likely be best to predict the market share of various technologies, learn costs accordingly, calculate TARFs, apply the technology and adjust costs as necessarily to reflect lesser or greater application of each technology.

The model documentation on page 13 has been corrected.

The fuel savings are those believed to be valued by the consumer when purchasing a new vehicle. The user sets these savings primarily through the payback period. The model then discounts the savings using the standard economic discount rate used elsewhere in the model. If the user believes that a consumer discounts fuel savings at a greater or lesser rate, she or he can adjust the estimated payback period to reflect the fact that the model uses a different discount rate in this calculation.

- Calculation of compliance to Attribute-based standards:
  - An overarching feature of the methodology is that progress in reducing GHGs/fuel-use occurs by advancing drivetrain technology and other attributes largely transparent to the consumer. Technologies are sequenced based per-vehicle figures of merit, assuming no impact on vehicle designs (apart from fuel use technology) and constant vehicle sales shares. One issue to consider is whether these assumptions of unchanged vehicle and unchanged sales mix become less defensible for attribute standards like the footprint standard.
  - On page 7, equation for the logistic-based footprint, there appears to be a sign error in the denominator (should be $1+\exp((x-C)/D)$ not $1-\exp((x-C)/D)$). This is likely a typo in the documentation alone.
- Calculation of compliance to possible market-based standards
  - No discussion or provision for market-based (permit trading) standards is yet made. This should at least be acknowledged.
  - One strategy for doing more flexible standards would be to simply merge the datasets and technology-sequence stage for all manufacturers and vehicle types in a trading group. However, this would not provide information about potential permit prices and burdens across manufacturers.

Response: EPA believes that the vehicle sales mix will actually be less affected by attribute-based standards compared to universal or flat standards. A universal standard encourages smaller vehicles. An attribute-based standard applies a more stringent standard to smaller vehicles, negating some or all of the natural reduction in GHG emissions which comes with reducing vehicle size and weight. In either case, the relationship between consumer purchase preferences, vehicle cost and fuel economy is very complex and not well assessed. A number of models have been developed to simulate these relationships, but they appear to differ substantially, especially regarding consumers' valuation of fuel economy. EPA may incorporate such effects into future versions of OMEGA. However, a first step in this direction would be to couple the two types of models and run them iteratively and see if they converge.

The documentation of the constrained logistic curve formula has been corrected.

The inclusion of permit-based trading beyond the light-duty vehicle market is currently beyond the scope of the model. We agree with Dr. Leiby that the user could simulate the net impact of flexible credit trading across manufacturers by labeling all vehicles with the same manufacturer name. In addition, examination and analysis of the compliance cost per vehicle should provide sufficient information to estimate the permit prices implied. However, the user would have to develop these algorithms.

4) The congruence between the conceptual methodologies and the program execution (examining the results with good engineering judgment)

- This is difficult to assess and a careful validation of this model's execution would require further examination. The results appear generally reasonable, but that is a weak test.
- I was only able to experiment with cases for one design cycle. The longer-term cases involving multiple design cycles are more challenging. It has been noted the model solves for design cycles independently of one another. So it would be worthwhile to test what this implies for the sequence of technologies used from one cycle to the next.
- One observation is that the inclusion of the non-compliance FEE does affect the model solution and choice of technologies. As mentioned above, the theoretical justification for this is not well formed, given that all manufacturers are typically assumed to end in compliance. However, I did not that the impact of including the FEE is modest, only changing per-vehicle costs by a few dollars. However, for at least one manufacturer (#9) the cost and technology sequence changes significantly. I am not sure this is a desirable outcome.
- Also, simple tests with the sample dataset show a relative insensitivity to the choice of TARF. This was surprising, and needs more investigation.

Response: The limited role of the FEE was discussed earlier. We assume that Dr. Leiby is referring to an insensitivity of the TARF to a change in the value of the FEE. This is not surprising, since the CAFE fine of $55 per mpg is much smaller than the fuel savings associated with a 1 mpg change in fuel economy. The level of the FEE has little effect on the order of technology application since it tends to reduce the value of the TARF for all technologies roughly proportionately to the fuel savings already included in the TARF calculation.

5) Clarity, completeness and accuracy of the calculations in the Benefits Calculations output file, in which costs and benefits are calculated;

- This system produces a large number of useful side calculations.
- Again, further investigation is necessary to investigate their accuracy.
- Overall, a careful independent validation of the two phases of this model's execution (manufacturer compliance simulation and effects calculation) would be well worthwhile.

The code for compliance simulation is compiled and not visible. Working through the logic in the post-processing calculations of the BenefitsCalculation spreadsheet would take a bit of time. But it would be worthwhile. Overall a useful validation effort could probably be complete in about a week of focused attention.

Response: The inclusion of a value in the benefits calculation is not meant to automatically convey accuracy. This will be clarified in the model documentation. The user is ultimately responsible for all input values used in the modeling. Of course, if the user uses an input file published by EPA in some context other than simply providing an example, then the EPA analysis referencing that model run will support the choice of values used. As Dr. Leiby noted above, review of the inputs to the model or benefits calculation spreadsheet was not part of the peer review charge.

EPA's publishing of the results of its OMEGA modeling and estimated benefits of the proposed vehicle GHG standards should accomplish much of the task referred to in Dr. Leiby's last comment, as such inputs and outputs will be subject to a full review by the public during the comment period for that proposal.

6) Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed; and

- The XML format for data transfer and display is a very good design choice, allowing flexibility, modern data-exchange capability, ready output to internet, and easy extension of the report.
- This display in the visualization output is useful overall, but it seems more oriented toward "expert users" who are willing to wade through details to find understanding and the information they need.
  - TechPack are reference by number only, but perhaps could easily be labeled with the full name or 4-character abbreviation, or cross-reference by hyperlink to a description of the technology.
  - Additionally, hyperlinks could be added that would allow the user to easily jump to the table for a particular manufacturer or vehicle type.
- It would be very helpful to have some graphical summaries of the input and output results.
- All output files should embed clear documentation on the inputs used. E.g.
  - The .log file does list names of the 4 input files, which is essential.
  - The "Visualization Output" file does not (yet) report the input files (but the information could be retrieve from the XML file).

EPA has improved the formatting of the output files, including better labeling of technology packages which have been applied. We will consider the use of hyperlinks and graphical outputs in the future. Output files now include date and time stamps plus the names of the input files used.

7) Recommendations for any functionalities beyond what we have described as "future work."

- Clearly defined improvements that can be readily made based on data or literature reasonably available to EPA
    - First I note that there were multiple references to "future work." It may be helpful for EPA to construct a list of these prospective improvements, and establish priorities and a staged, progressive approach for revision. Specific releases of the model with carefully specified functionality will allow prospective users at EPA and elsewhere be clear about what the model is and can do at any point in time.
    - While the model has a number of valuable aids to execution and reporting (input validation, automated generation of run logs, XML data, and "Visualization" tables for web/browser display), more could be done here to improve usability and provide greater insight about each case run. Comparatively simple revisions and extensions to the operational procedures and output could be well worthwhile.
        - Provision for side-by-side case comparisons, reporting or graphing difference.
        - Case management and logging facilities.
            - Currently the system labels every file with generic name concatenated to a time-date stamp. Very quickly a directory can be cluttered with cryptically named log, xml, htm files.
            - A case archiving facility, that compresses all input and output files to document the case, might be useful
            - The ability to specify a CaseName in the Scenario file, that then becomes part of each output file, would also be helpful.
            - When the VGHG.exe file reads a scenario file, it does not record, or at least display, the name of the file read. It is easy to forget which case was read if you step away, or are doing many cases.
            - Relatedly, the purpose of the VGHG.exe's separate menu options is not yet clear to me.
                - It seems that once a scenario and the associated datafiles are read, execution would be the logical next step. The scrollable tables from data input are really too constrained a view to allow useful review or verification of the data.
                - Once the case is run, it seems "Save" to XML might be automatic, otherwise one is limited to the text-based log files, that omit summary information. "Saving" seems needed for Visualization and Benefits Calculation in the spreadsheet.
                - So perhaps VGHG.exe might load-run-save in one step, although I may be missing something important.
        - Graphical capabilities [more thought required here about exactly what graphs would be most useful. But there are many data in the tables, and they are not simple to process mentally.]
- Improvements that are more exploratory.
    - Extension to accommodate flexible/market-based emission or fuel-economy regulations.

  - Permit trading extensions, constructed by pooling selected vehicle types/classes, and/or manufacturers, during the compliance phase of the analysis.
  - Ex post calculation of implied permit prices based on marginal costs of compliance (measured by the cost/GHG reduction of the final technology pack applied).
  - Ex post calculation of economic implications for individual manufacturers, by comparing results with and without trading/pooling, and accounting for the implied costs and revenues from permit exchanges between manufacturers.
- Extensions to consider endogenous (standards-induced) changes in vehicle attributes. These are a higher challenge, but would be very valuable for an improved understanding of the market responses to regulations.
  - Endogenous changes in sales volume/mix
  - Endogenous changes in vehicle size/footprint

Response: EPA appreciates these suggestions and will consider them for future model development activities

C. Comments by Dr. Jonathan Rubin

I would like to congratulate the EPA for undertaking to build this tool which will be very useful for possible regulatory compliance and anticipated and unanticipated policy analyses. The construction of such a tool requires extensive expertise, professional judgment, necessary compromises and assumptions. The validity of the output will of course depend on these factors as well as the data available to populate the model.

My comments are based on my review of the materials provided to me by Southwest Research Institute: the EPA vehicle GHG Emission Cost and Compliance Model Description and associated attachments and appendices and the VGHG model and the associated spreadsheets. These comments reflect my understanding of EPA's possible use for this model for regulatory compliance as well as use by external researchers and policy analysts who may use the model for analyses of state and regional policies.

My comments below respond to the particular questions posed in the transmittal letter from Southwest Research Institute.

Overall Approach to the specified modeling purpose and the particular methodologies chosen to achieve that purpose

The authors have clearly put in a great deal of work on this challenging project and should be commended for an excellent start. That said, more effort and thought needs to go into what I call the accounting stance. On page 2, line 42-43 (p. 2, l. 42-3) the documentation states that "The primary cost of the GHG emission control is the cost of the added technology compared to the baseline." My question is: "cost to whom?" Costs to consumers will differ from costs to society or costs to manufacturers. At times, the documentation reads as though these are costs to manufacturers – since CAFE fines are considered; other times the costs seem to be towards consumers or society. These accounting stances will differ for several reasons: 1) private and social discount rates differ, 2) social and private risk differs (on average technology performs as well as expected, but not for each vehicle), 3) subsidies to purchase plug-in vehicles or other advanced technology vehicles drive a wedge between private and social costs, 4) subsidies to biofuels and electricity at the state level (exemption for some or all road-use tax) mean that consumer costs are not equal to full resource costs. Clarifying the accounting stance is a high priority, because many further calculations rely on its clear definition.

Since the potentially regulated agents are vehicle manufacturers, my recommendation is to define costs as the costs to manufacturers of incremental technology and vehicle re-design costs. The net costs to manufacturers are equivalent to the incremental costs of fuel economy technology less any increase in retail prices that manufacturers can charge for more fuel efficient vehicles. This should be equal to some portion of the expected fuel savings plus any changes in the hedonic value of vehicles due to changes in vehicle performance, noise, size, and refueling time (more on this later). By separating out manufacturing costs more clearly from consumer valuation of vehicles, the presentation will be more transparent. This also will make clearer the distinctions between consumers' rates of discount from manufacturers' costs of capital from society's rate of time preference.

Additionally, I recommend that the *net* costs clearly incorporate and identify all subsidies (for electric or plug-in hybrid vehicles and alternative fuels) but display costs and benefits separately to private agents (manufacturers, consumers) and society. These will generally not be the same. For example, the benefit calculation spreadsheet "Externalities" adds together consumer money saved on fuel with savings from lower oil imports. I would be very surprised to learn that the assumptions of the discount rate or risk premium or both in the calculation of benefits of reduced crude oil imports are the same as consumers' discount rates for expected future gasoline savings.

Response: Broadly speaking, the model is designed to project the application of technology which is controlled by the manufacturer of the vehicle, but which is also influenced by consumer preferences and governmental requirements. Then, once this technology has been selected, the model sums up the costs and benefits associated with the application and use of this technology from the view of society in the benefits calculation spreadsheet. This is consistent with EPA's approach to the estimation of costs and benefits in its mobile source rulemaking analyses, including the recently proposed vehicle GHG standards. EPA often evaluates costs and benefits using two or more discount rates, reflecting the time value of money from different perspectives (e.g., private and public). The user of the OMEGA model can perform this task by modifying the discount rate in the benefits calculation worksheet after the results for any particular OMEGA model run have been loaded. In the analyses supporting the proposed vehicle GHG rule, EPA developed technology costs which are based on piece costs, the cost of assembly plus an intermediate markup factor which accounts for indirect corporate level costs and a reasonable level of profit. These costs were used in the OMEGA model to estimate the average cost of added technology per vehicle for the rule. Thus, they were used to represent the cost per vehicle from both manufacturers' and society's perspective. As EPA develops the OMEGA model further, particularly if the explicit treatment of capital investment requirements is incorporated in to the technology application process, it may be more important to explicitly treat technology costs differently depending on entity experiencing the cost (e.g., manufacturer, consumer, society).

A special case where such separate treatment of costs could be very important is the availability of subsidies of the purchase of vehicles equipped with certain technologies (e.g., plug in hybrids, electric vehicles, etc.). As discussed further below, if sizeable subsidies apply to vehicles equipped with technologies which are being added by the model, these should be reflected in the manufacturer's choice of technology. Currently, the model does not facilitate the availability of purchase subsidies. Their existence must be addressed by using different costs per vehicle when technology is being selected and when societal costs are being determined.

In addition to the use of these costs when summing up the cost of technology at the vehicle, manufacturer and industry levels, the model also uses the same technology costs to calculate the TARF, which is in turn used to decide which technologies get applied to specific vehicles. The TARF does not necessarily reflect the perception of costs by society. The two TARFs currently included in the model are intended to reflect the decision making of a manufacturer and thus, reflect costs from the point of view of the manufacturer. Since the manufacturer must satisfy its customers and regulatory mandates, a manufacturer's decision making processes will reflect these needs, as well. More explicitly, the technology cost is the full cost of that technology at the consumer level, including research and development costs, amortization of capital investment, etc. This cost is generally the same cost as EPA estimates in its regulatory support analyses when estimating the cost of new standards. This cost is not necessarily the increment in price that the manufacturer would charge for that technology, since price is a function of many factors which can change fairly quickly depending on market conditions. The fuel savings are those valued by the customer, so they are based on fuel prices including taxes and reflect the timeframe which a customer might consider when purchasing a vehicle. The residual value of the added technology is not currently reflected in either TARF, but could be added in the future. The rationale behind the TARFs will be clarified in the model documentation to reflect these points.

The same technology costs are used in summing up the cost of all the technology which is applied to vehicles in benefits calculation worksheet. This is consistent with the treatment of technology costs in regulatory analyses supporting recent EPA rulemakings, including the recently proposed vehicle GHG standards. These analyses often develop the consumer level costs from material costs, labor, capital investment and profit at the supplier and manufacturer level.

The current OMEGA model does not account for the availability of subsidies toward the purchase of certain types of vehicles, such as PHEVs or EVs. Such subsidies clearly affect the consumer's valuation of these vehicles and the likelihood that manufacturers would implement these technologies. In terms of the model's proceses, these subsidies change the cost of technology as perceived by the consumer as reflected in the TARF. A user could reflect this by including the subsidy in the cost of these technologies in the Technology file. The OMEGA model would then apply the technology considering the subsidized price. The user would then have to add the value of the subsidy to the costs as estimated in the benefits calculation spreadsheet (and other output formats) in order to fully estimate societal costs. This limitation does not affect EPA's use of the OMEGA model in support of its proposed vehicle GHG standards, as none of the technologies projected to be required currently receive subsidies. However, this issue could be important for analyses evaluating vehicle GHG standards further out into the future. EPA will consider ways to incorporate such subsidies into future versions of OMEGA.

2) The appropriateness and completeness of the contents of the sample input files.

d) The elements of the Market input file, as shown in Appendix 1 of the model description, which characterize the vehicle fleet

If the data are available, it would be useful to have the cross-price elasticities for makes and models or model segments such that mix-shift impacts could be taken into account as vehicle prices rise in response to additional technology packages.

Some of the market data are interesting, but do not seem necessary. For example, what is the use of knowing a vehicle's structure (e.g., unibody) or the maximum seating capacity?

Does the market spreadsheet contain data for mid-size trucks, gross vehicle weight 8,500 - 10,000? If not, I would think it should, given that they are now covered under the revised light truck CAFE rules.

Response: EPA agrees that it would be desirable at some point to incorporate the impact of increased vehicle cost, improved fuel economy and other factors on vehicle sales. However, this is beyond the scope of the OMEGA model at this point. The relationship between consumer purchase preferences and vehicle cost and fuel economy is very complex and not well assessed. A number of models have been developed to simulate these relationships, but they appear to differ substantially, especially regarding consumers' valuation of fuel economy. EPA may incorporate such effects into future versions of OMEGA. However, a first step in this direction would be to couple the two types of models and run them iteratively and see if they converge.

As mentioned in Section G of Mr. German's comments, the current market file format includes several vehicle parameters, such as weight, seating capacity, etc., which are not currently used by the model. These aspects of the vehicle were included in the Market file as place holders for potential attribute based standards which could be based on these factors. We will modify the model documentation to clarify that these data fields are not used by the model.

The example market file provided the peer reviewers does not necessarily include all vehicle classes potentially addressed by future GHG regulations. The OMEGA market file which will be published as part of EPA's proposed vehicle GHG rule will include medium-duty passenger vehicles which are above 8500 pounds GVWR.

e) The elements of the Technology input file, in Appendix 2, that constrain the application of technology

Are the incremental costs shown in column X retail or wholesale? What do they assume about the volume of production? If I read the file correctly the incremental price for plug-in hybrid technology often has a low first cycle cap of 5%. Is the incremental cost of this technology consistent with its use on 5% of a market segment of a given manufacturer? It is important to clearly define the relationship between scale of use and incremental technology cost. The columns "a", "Decay", "seedV", "kD", and "cycle learning available" need further clarification.

P. 2, l. 14 notes that the GHG target can be set as a function of vehicle footprint. The technology input file does not show an indication of how down-weighting and changes in footprints may be used to meet a set of given standards. This may not be able to be accomplished immediately given available data, but it should be considered as more experience with the footprint standards is gained from CAFE compliance.

Response: Please see the response under Section #1 above for a discussion of how technology costs are treated in the model. As described in the peer review charge, the specific inputs provided to the reviewers were for example purposes only. Therefore, they do not represent any particular sales volume. EPA has published the Technology file which it used in its OMEGA modeling in support of its proposed vehicle GHG standards. This file contains official EPA cost estimates and the Draft Joint Technical Support Document for the proposed rule describes how they were developed.

We agree with Dr. Rubin that the model documentation did not describe how the Initial Incremental Cost, α, Decay, seedV, kD, and Cycle Learning Available fields are used in the model. These inputs are related to the prediction of cost reductions due to learning, which has not yet been implemented in the model. These columns appear in the Technology file as place holders for future version of the model.

Weight reduction can be a technology which is input to the model or part of a broader technology package input to the model. The effectiveness and cost of this weight reduction is estimated in the same manner as any other technology. EPA included weight reduction in the technology packages which it evaluated in support of its recent proposed vehicle GHG standards. In doing so, EPA held vehicle size, footprint, utility and performance constant.

It is currently not possible to include a technology in the model which changes a vehicle's footprint. The TARF for such a technology would be quite complex, since both the manufacturer's corporate-wide emission standard and the vehicle's emissions would change simultaneously. It is possible that the technology could move the manufacturer further from compliance. Such a change would also likely change a vehicle's utility and its perceived value. Thus, this would be a step towards projecting a change in sales mix as a function of technology cost, which is currently beyond the scope of the model. It is possible that such capability could be added in the future.

f) The definition of the standard and economic conditions in the Scenario input file, as shown in Appendix 3

As per my earlier comments, I think there ought to be a place for 3 different discount rates: consumers, manufacturers and society. Similarly, their ought to be a places for payback periods for consumers and society.

Response: As mentioned above, the TARF calculation focuses on the point of view of the manufacturer. As discussed in Section 1 above, a manufacturer may view technology costs differently than society. This difference can be reflected in the development of the per vehicle technology cost (i.e., the amortization of any capital equipment or other investment required to implement the technology). In the TARF calculation, the technology cost occurs at the time of vehicle purchase, so it is not affected by the discount rate assumed. The treatment of the increased cost of vehicles across model years occurs in the benefits calculation spreadsheet. The costs and benefits addressed there are intended to reflect those of society. Thus, use of societal discount rate is appropriate at that point.

The primary place where a consumer discount rate comes into play is in the value of the fuel savings in the TARF calculation. It is likely that the typical new vehicle purchaser discounts fuel expenditures differently than society. However, the user also has the flexibility to set the payback period over which these fuel savings are determined. To the degree that the consumer discount rate differs from the societal discount rate, the user can adjust the otherwise appropriate payback period to compensate.

d) The elements of the Fuels input file, as shown in Appendix 4, which characterize the fuel types, properties, and prices

It would be useful to reference the data sources for many/most of the data items. For example, energy density – please see EIA report XYZ. The value shown for gasoline, for example, at 115,000 is different than that published by the USDOE, *Transportation Energy Data Book* v 27 (Davis, Diegel, Boundy, 2008, Table B4), which shows a (lower heating) value of 115,400 Btu/gallon.

The units should also be displayed for all inputs. Again, using the gasoline example, being familiar with the data, it is clear that the unit of analysis is Btu/gallon (lower heating value). For other data, the units are less obvious. For electricity, the input file or the documentation, or both, should give the assumed conversions from kilowatts to energy density or motive energy such that users can adjust for different end-use efficiencies. Also for electricity, the assumed grid mix should be given with conversion rates such that users can make appropriate adjustments for different policy analyses.

I do not see a statement indicating whether the fuel price data is in nominal or real dollars.

I do not see a row for ethanol giving its energy density, mass, and density. I am assuming that fuel type "EL" is electricity. Also, should you not have at least two types of ethanol – corn and cellulosic – with different price paths?

As I indicated in my earlier comments, I think it is important to explicitly note the role of subsidies when determining costs. Given this assertion, the fuels data file ought to explicitly note federal and state average subsidies (i.e., the federal blender's tax credit and foregone state excise taxes) for ethanol and other alternative fuels. As I note below in 7) Extended Functionality, accounting for foregone taxes is a logical addition to the model, especially when considering plug-in electric hybrid vehicles.

Response: We will attempt to document the values contained in the input files distributed with the model. This has been done for the input files published with the proposed GHG vehicle standards. However, some of the inputs are for example only. This will be indicated in the model documentation.

Incorporating the units of the various input fields into the input file headings themselves involves changes to the core model. In the near term, we have included detailed descriptions of each type of input value in the model documentation for easy reference by the user.

Fuel prices are intended to be in terms of real dollars. This will be clarified in the model documentation.

The current version of OMEGA focuses on gasoline, diesel fuel and electricity because the vast majority of current vehicle sales are certified on these fuels. Very few dedicated alternative fueled vehicles are sold and flex fuel vehicles are certified on either gasoline or diesel fuel and numerical adjustments made to their fuel economy or emissions to reflect incentivizing regulatory credits.

Current legislation and enabling EPA regulations encourage the use of renewable fuels. However, to date, these requirements are not integrated with the regulations governing vehicle fuel economy, nor the recently proposed vehicle GHG standards. Thus, the primary place which they intersect with the OMEGA model is in the calculation of benefits. As this is done in a spreadsheet, the user could easily modify the calculations to reflect an anticipated use of renewable fuels over time. EPA may develop a standard version of the benefits calculation spreadsheet in the future which facilitates this use. However, as suggested by Dr. Leiby, this is not a first order priority at this time. It is not clear, however, that two types of ethanol would be needed. The price of ethanol in each calendar year would simply have to reflect the price expected given the two sources of ethanol. The upstream emissions would also reflect the mix of the two production paths.

The model currently does not convert electrical energy into liquid fuel energy or vice versa. The two types of energy are tracked separately. The benefits calculation spreadsheet currently only tracks gasoline use. The capability to track diesel fuel and electricity use will be added soon.

We plan to reflect fuel excise taxes in the benefits calculation in the near future. Changes in these taxes could then be tracked separately from changes in fuel costs from a societal perspective.

e) The reference data contained in Appendix 5 which are currently hard-coded into the model but, in the very near future, will be contained in a user controlled input file.

The Exclusive Inputs spreadsheet anticipates E10 and E85. It would seem fairly straightforward to allow for other blends such as E15. The proportion of the ethanol that comes from cellulosic sources in each year should be accounted for such that upstream CO_2 emissions can be properly credited, similarly for petrodiesel and biodiesel.

Response: EPA agrees that when ethanol blends and other renewable fuels are added to the benefits calculation spreadsheet, it would be reasonable to include the annual split of ethanol from corn and cellulosic feedstocks.

3) The accuracy and appropriateness of the model's conceptual algorithms and equations for technology application and calculation of compliance;

On p. 9, l. 40, the documentation states: "The core model then adds the effectivenesses and the costs of the technology addition until each manufacturer has met the standard or until all technology packages have been exhausted." Given that existing law allows credit averaging across all vehicles sold by a manufacturer, this requires that compliance would be checked through an iterative routine. Please describe this routine including mechanisms to prevent cycling so that convergence is assured.

p. 10. VMT is given by: $VMT = SurvivalFraction * AnnualMilesDriven$. I believe this is this done by vehicle class (from the data file). The documentation should index the function with separate subscripts.

p. 10. Discounted VMT. I have two issues with this calculation. The first is mechanical. Why

$$VMT_{D,FS,i} = VMT_i \times \frac{1+\frac{DR}{2}}{(1+DR)^i}$$

does the numerator have the term 1+DR/2? Is the discount rate not understood to be the simple annual rate? (Also what do the indices D and FS represent?). Conceptually, however, I do not think this VMT should be discounted. Costs and benefits are appropriately discounted, but I think it is a mistake to discount a physical calculation. It blurs the distinction between consumer and society valuation of VMT and can lead to misleading outputs.

This point is further emphasized by calculation of VMT for GHG calculations (p.11)

$$VMT_{D,CO2,i} = VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i}$$

, where VMT is enhanced by the rate in change in the value of

CO_2, IR. I strongly suggest that this equation be re-done to separate out measurement of physical units (VMT) from cost and value calculations.

p. 11. RCO2

$$RCO2(g/mi) = \frac{\sum_{i=1}^{\substack{Lifetime\\(years)}} \text{RefLeakage}_i \times GWP}{\sum_{i=1}^{\substack{Lifetime\\(years))}} VMT_{D,CO2,i}} = \frac{\sum_{i=1}^{\substack{Lifetime\\(years)}} \left[LeakRate_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right] \times GWP}{\sum_{i=1}^{\substack{Lifetime\\(years)}} \left[VMT_i \times \frac{1+\frac{DR-IR}{2}}{(1+DR-IR)^i} \right]} = \frac{LifetimeLeakage \times GWP}{LifetimeVMT}$$

I have two comments. First, it seems to me that, as with VMT, the numerator ought to be multiplied by the survival function. Second, as with VMT, the leakage rate ought not to be adjusted by DR and IR. Also, again, I do not understand the form of the adjustment – why multiply the numerator by 1+ (DR-IR)/2? Should not the GWP be indexed by i?

p. 12. Determine the order of Technology Application. On the previous page the subscript *i* represented "year" here it represents technology package. The use of subscripts should be unique throughout the documents.

P. 12. Intermediate calculations for each vehicle type. It appears that the subscripts have changed again. CO2 is indexed by t and AIE, RIE are missing subscripts altogether.

p. 13. Calculate the fuel consumption before and after technology additions.

$$FC_{t-1} = \frac{CO2_{t-1}}{CD_{t-1} \times \left[\frac{44gCO2}{12gC} \right]}$$

. Given that CD is in units of carbon, this equation looks unit-less (CO2/CO2). Where do gallons per mile units come in?

P. 13, l. 18. In step iii, calculating fuel savings we see the following equation.

$$FS = \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i} \right)_{t-1} - \left(FC_1 \times \sum_{i=1}^{PP} \frac{FP_1}{i} + FC_2 \times \sum_{i=1}^{PP} \frac{FP_2}{i} \right)_t$$

First, why is FP divided by *i*? Second, where is the adjustment for vehicle age? How does this equation account for consumers' choosing to drive more miles using one fuel v. another? (Consumer's may want to maximize the time they spend in electric power mode.) Even if the data do not exist to parameterize the model yet, I suggest that the functionality be built in to allow for consumers' choosing to use one fuel type or another.

P. 20, l. 38-46. In calculating the impact of the reduced time required to refuel vehicles, I do not see a mention of the estimated driving that will occur using electricity in PHEVs.

Response: The model does not currently require any iteration to determine compliance after each step of technology addition. Prior to technology addition, the model determines the corporate average standard for the manufacturer's fleet of vehicles. The model then checks to see if the manufacture complies with its baseline vehicles coupled with vehicle sales in that redesign cycle. If so, the model does not add any technology. If not, the model begins to add technology to individual vehicles using the TARF to make it decisions. After each step of technology addition, the model recalculates the manufacturer's corporate average emission level to determine if compliance has been achieved. This continues until compliance is achieved or there is no more technology to apply.

The issue of discounting the CO2 emission reduction is discussed in Section 1 of Dr. Leiby's comments. Discounting has been removed from the CostEff TARF which takes the point of view of the manufacturer. However, we are considering leaving the discounting in for a third TARF, which would take the viewpoint of society. In theory, it is the value of CO2 emissions which is being discounted. However, since the base value of CO2 emissions would be the same for each TARF, its inclusion in the formula has no effect on the relative TARF ranking. Thus, we will continue to simply discount emissions. This will be explained in the model documentation.

The inclusion of the factor of one plus one half of the discount rate is to discount to the middle of the year, to recognize that emissions occur throughout the year and not at the end of the year.

CO2 emissions from the tailpipe occur in proportion to VMT. Thus, the measurement or calculation of CO2 emissions per mile is straightforward. Refrigerant emissions do not occur in proportion to VMT. These emissions can be placed on a per mile basis, but only by measuring or calculating refrigerant emissions over a period of time and dividing by the typical amount of driving occurring over that period of time. Also, due to gradual vehicle scrappage and a gradual reduction in VMT per year as vehicles age, CO2 emissions are somewhat front-loaded towards the beginning of a vehicle's life. In contrast, refrigerant leakage is near zero when the vehicle is new and increases as the system ages and begins to leak. Therefore, when putting lifetime refrigerant emissions on a per mile basis, it is important not to simply divide by the vehicle's lifetime miles, but to also consider the timing of these miles through discounting. This places a unit g/mi reduction in both tailpipe CO2 and refrigerant emissions (in terms of their CO2 equivalent) on a comparable basis. The suggested changes to model documentation have been made.

The equation for fuel consumption (FC) is correct. CO2 represents CO2 emissions per mile and CD represents grams of carbon per gallon of fuel. Thus, the units of FC are gallons of fuel per mile.

The equation for fuel savings in the model documentation is incorrect. (The equation in the model itself is correct.) The fuel price should not be divided by i. Instead, it should be divided by the payback period. Also, the fuel price should be a function of calendar year (i.e., be subscripted with "i". This will be corrected in the model documentation.

The reduction in refueling time does not yet consider the impact of recharging PHEV batteries. This will be noted in the model documentation. Future versions of the model will reflect an estimate of the time that it takes to connect and disconnect the vehicle to an outlet, probably each action performed once per day.

4) The congruence between the conceptual methodologies and the program execution;

As suggested, I made changes to input values in the spreadsheets and re-ran the model. The changes as displayed in the benefits calculation spreadsheet were what I had qualitatively expected.

5) Clarity, completeness and accuracy of the calculations in the Benefits Calculations output file, in which costs and benefits are calculated;

Please see my comments in the beginning of the document. I believe that the benefits calculations should more clearly reflect benefits and costs to three different agents: manufacturers, consumers and the nation.

Recognizing that the benefits data (Benefits Calculation workbook) is subject to change, it would be really useful to list the data sources for all inputs. For example, if the VMT data is coming from MOBILE6, the VMT_Lookup spreadsheet should clearly state MOBILE6 as its source and similarly for the other inputs and spreadsheets.

Similar to the formula used to discount VMT, the spreadsheet "ExternalVMTCosts($)" discounts externalities using the formula: $\frac{1+\frac{DR}{2}}{(1+DR)^i}$. My question is why? Most commonly used discount factors are simple $\frac{1}{(1+DR)^i}$ annual rates. In some senses it does not really matter because the user can set the discount rate, but by using a non-standard discount rate this is likely to lead to unnecessary confusion.

In the "Benefits Calculation" workbook, the worksheet, "Emissions_Fuel Conservation" shows upstream savings from NOx, VOC, CO, PM, and SOx. These emissions savings are all calculated based on upstream conventional gasoline emission savings. I would think that either: 1) these should be based on a weighted average of gasoline, diesel, ethanol, and electricity upstream emissions, or 2) the gallons saved should have been weighted gallons. I cannot readily determine if the saved gasoline gallons are weighed by the proportion of gasoline, electricity, ethanol and diesel (and the weights would be emission-gallon weights.) This needs to be clarified or corrected.

In the "Benefits Calculation" workbook, the worksheet, "ExternalVMTcosts($)" displays the discount factor applied to future costs as the common discount factor used throughout the model. As I earlier suggest, society's rate of discount for accidents costs (human life) are not likely to be the same as consumers' rate of discounting future gasoline savings. These should be separate inputs.

In the “Benefits Calculation” workbook, the worksheet, “DownstreamCosts($)”, the units on CO2 are shown as “$/ton”. I believe that the label is missing the modifier, “metric”.

In the “Benefits Calculation” workbook, the worksheet, “UpstreamCosts($)” shows benefits determined for CO, VOC, NOx, SO2, PM2.5 all based on emission factors for conventional gasoline. As per my earlier comment, I think these ought to use separate emission factors for each fuel.

In the “Benefits Calculation” workbook, the worksheet, “All Costs” shows costs in aggregate for the nation. It would be useful to also display the average, per vehicle costs.

Response: Dr. Rubin’s comments referring to the calculation of costs and benefits to manufacturers, consumers and society, referencing input values, and discounting procedures are addressed in previous sections. As mentioned above, the primary focus of the benefits calculation spreadsheet is the estimation of societal costs and benefits.

The benefits calculation spreadsheet currently assumes that all changes in fuel consumption are in terms of gallons of gasoline. The properties of and emissions from the production and use of this fuel can and should consider that “gasoline” in the U.S. includes a substantial volume of ethanol. This is clearly an approximation, but a reasonably good one for the light-duty motor vehicle fleet in the U.S. The explicit consideration of the cost and emission impacts related to other fuels will be added to a future version of the benefits calculation spreadsheet.

Labeling of units in the benefits calculation spreadsheet has been made more specific. “Metric” has been added, where appropriate. We agree that displaying the average cost per vehicle would be useful. Other model output files show this figure, but the benefits calculation spreadsheet should, as well.

6) Clarity, completeness, and accuracy of the model's visualization output, in which the technology application is displayed; and

In displaying the results Average Incremental Costs, please round to the nearest dollar; showing two digits to the right of the decimal point gives a false sense of precision and makes the output harder to read.

Response: We agree that showing costs in terms of dollars and cents is overly precise. This will be revised.

7) Recommendations for any functionalities beyond what we have described as "future work."

The model (VGHG) window box should be made larger – perhaps fill the screen. It is really too small to perform step 4 in running the model (i.e., Verify that the correct data has been populated into the VGHG model). There is also no side-to-side scroll to see the whole data field.

Given the renewable and advanced biofuel requirement in the Energy Independence and Security Act of 2007, it would seem that the model ought to have data input fields to allow users to specify the quantities (or proportions of total fuel) of ethanol and biodiesel used in each year. Moreover, the proportion of biofuels which come from cellulosic sources should also be able to be specified. Accordingly, the GHG emission accounting framework will need to capture that proportion of the reductions due to changes in vehicles and that proportion due to changes in fuels. In anticipation of future developments in the biofuels market, it may be worthwhile to build in placeholder functionality to account for domestic versus imported biofuels or biofuel feedstocks.

The model would be significantly enhanced if it were made probabilistic. Given that input data contains underlying uncertainty (What is the actual cost of a given technology? What will be the price of gasoline in 5 years?), the model should be made to run hundreds or thousands of times using Monte Carlo analysis on some of the key input data to generate a distribution of outcomes. Even if this is not done in the near term, having the output columns show results for “high and low” cost/interest rate scenarios would be convenient. It would save having to run the model multiple times and pulling the results in to some other summary worksheet.

The documentation notes (p. 2) that the primary cost of the GHG emission control is the cost of the added technology as compared to the baseline. I do not think this is a valid presumption for large changes in GHG emission control. The NRC’s study on CAFE assumed that vehicles were hedonically equivalent. Given the likely wide-spread adoption of diesel technology and, quite possibly, plug-in hybrid vehicles (PHEVs), vehicle driving experiences are not likely to be the same. Quite possibly, PHEVs will provide a superior level of driving satisfaction. If vehicle manufacturers downsize or reduce performance (acceleration) to meet compliance, vehicle satisfaction could diminish. I do not have a good suggestion on how to adjust for these possible hedonic costs or benefits. Perhaps the model could incorporate placeholder equations that would allow users to specify hedonic gains and losses. Nonetheless, the model documentation should be forthright in acknowledging this limitation.

The model should provide for an estimate of the likely gasoline excise tax implications for different levels of GHG emission reduction. Particularly useful would be to present this information in the context of different compliance strategies. For example, with tax credits for PHEVs, and no change in federal gasoline excise tax policy, the revenue losses could be significant. This functionality could be very useful for policymakers.

As described in the documentation, the model development foresees an increased ability for users to change input assumptions. Changes to these assumptions may have significant impacts on costs and GHG emission reductions. It would be useful for the Model Reference Guide accompanying this model to describe in qualitative terms the impact of or assumptions behind choosing to adjust certain parameters. For example, the user manual could indicate that lowering the years of payback for technology would be consistent with a view that consumers only value the first years of fuel economy gains or place little or no value on GHG emission reduction that occur near the end of a vehicle’s lifetime. If practicable, it would also be useful to point out inconsistent choices.

It would be very useful to have the model output be available in units that are used internationally – grams CO_2 /kilometer or grams CO_2 equivalent/KM.

Clearly falling into the work for the future, would be to have a time profile of upstream CO_2 emissions for conventional gasoline and diesel reflecting regional or national low carbon fuel standards.

Response: EPA agrees that the dialog box would be more useful if it were larger and included the ability to scroll through the entirety of each input file.

The capability to perform probabilistic modeling runs is planned for the future. Of course, accurately reflecting the uncertainties involved in the cost and effectiveness of future technologies is a significant challenge aside from enabling the model to reflect such uncertainties. The modeling of discrete options, like several discount rates has already been made easier. The latest model version includes the ability to run multiple scenarios with one model run. Creating several Scenario files with differing emission standards, discount rates, payback periods, etc. is fairly simple. Comparing the results from these multiple cases still requires opening a separate output file from each run. EPA is considering an output file which would compare the output from several cases automatically. However, given the common format of the output, a user may also be able to develop a single spreadsheet which refers to the relevant cells of several output files and provides a quick comparison of the output of interest for several cases automatically.

The difficulty in simply and accurately reflecting changes in vehicle desirability and utility has already been discussed above. We will note this limitation in the model documentation when we describe the fact that the model holds the mix of vehicles constant during any particular model run.

The treatment of excise taxes was already discussed above under Section 2.d.

We appreciate Dr. Rubin's desire to have the model documentation aid the user in making good choices regarding input values. We will consider adding suggestions at various parts of the model documentation. This is certainly needed for the development of the values of TEB and CEB in the market file and the ordering of technology in the Technology file. However, OMEGA is not a model which is designed to be used by someone not experienced in the area of motor vehicle fuel economy and emissions and environmental and economic analysis. It will not be possible to provide a complete tutorial on all these topics in one model's documentation. If a user decides to modify a value from that which was published and supported by EPA, the user will have to support the appropriateness of that modification.

We agree that there would be some value to the presentation of emissions in international units. However, given the complexity of the benefits calculation spreadsheet using just one set of units, it would seem most appropriate to create a separate file which used a different set of units throughout.