FINAL PEER REVIEW REPORT

REVIEW OF CORPORATE AVERAGE FUEL ECONOMY (CAFE) MODEL AND SUPPORTING DOCUMENTATION

September 29, 2005

Background

On December 16, 2004, the Office of Management and Budget (OMB), in consultation with the Office of Science and Technology Policy (OSTP), issued its "Final Information Quality Bulletin for Peer Review" to the heads of departments and agencies (available at http://www.whitehouse.gov/omb/memoranda/fy2005/m05-03.html). This new guidance is designed to realize the benefits of meaningful peer review of the most important science disseminated by the federal government. It is part of an ongoing effort to improve the quality, objectivity, utility, and integrity of information disseminated by the federal government to the public.

To comply with these guidelines, NHTSA assembled a team of independent peer reviewers. The CAFE model and supporting documentation, used to support analysis for setting CAFE standards, was reviewed. NHTSA, with technical assistance from the Volpe Center, designed the model in support of a Notice of Proposed Rulemaking (NPRM) entitled "Average Fuel Economy Standards for Light Trucks; Model Years 2008-2011 (available at 70 Federal Register 51514; August 30, 2005).

NHTSA has determined that the model and supporting documentation is a highly influential scientific assessment as defined by OMB guidelines because its dissemination has significant public interest. Therefore, the peer review of the CAFE model and supporting documentation must comply with requirements of both Sections II and III of the OMB guidelines.

Selection Process

NHTSA selected reviewers from three disciplines to achieve balance in the expertise of the review. The reviewers are independent and each is from a different organization and none is currently an employee of NHTSA.

The selection process began with asking a number of individuals familiar with professionals working in the relevant disciplines to recommend possible reviewers. The candidates were then contacted with the review process, the schedule, the budget, and the need to avoid conflict of interest explained. Some candidates were unable to serve because of prior commitments, and other candidates removed themselves from consideration. NHTSA considered the qualifications and approved the following three reviewers:

Dr. Jonathan D. Rubin, Resource Economist
Interim Director, Margaret Chase Smith Center for Public Policy, University of Maine.

Ph.D., Agricultural Economics, University of California, Davis, 1993.
M.A., Economics, University of Washington, 1987.
B.A., Economics, University of Rochester, New York, 1984.

Dr. Rubin has extensive experience in the area of automotive transportation, including fuel economy research and energy modeling. Most recently, he designed and led a study focusing on tradable fuel economy credits for cars and light trucks.

Dr. Michael Q. Wang, Vehicle and Fuel Systems Analyst
Manager of Systems Assessment Section, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory

Ph.D., Ecology, University of California at Davis, CA. 1992.
M.S., Ecology, University of California at Davis, CA. 1989.
B.S., Agricultural Meteorology, China Agricultural University, Beijing, China. 1982.

Dr. Wang's extensive experience in vehicle and fuel systems analysis, coupled with his development of the GREET model, has set the industry standard for well-to-wheels analysis of vehicle/fuel systems.

Mr. Gary Rogers, **President and CEO of FEV Engine Technology, Inc.**

B.S.M.E., Northern Arizona University

Mr. Rogers possesses extensive experience in research, design and development of advanced engine and powertrain systems. He recently served on the National Research Council Committee on the Effectiveness and Impact of Corporate Average Fuel Economy Standards (NRC, 2002) where he chaired the technology subcommittee responsible for all technology assessments and predictive analyses for the potential for fuel economy improvement through the application of advanced technologies.

Review Process

The reviewers prepared individual reports. These reviews are included verbatim in this report. Specific views are not attributed to specific individuals.

Review #1

General Comments

The CAFE Compliance and Effects Modeling System (CAFE-CEMS) is a tool used to predict the application of efficiency-increasing technologies to specific vehicle models in response to changes in CAFE standards, and to calculate resultant CAFE levels among vehicle manufacturers. CAFE-CEMS also predicts the impacts on employment, energy use, criteria and CO2 emissions, total miles driven, and other monetary and non-monetary externalities from the light-duty vehicle sector subject to, and potentially subject to, changes in CAFE regulations. The system was developed to conduct analysis for rulemakings addressing CAFE reform and for setting standards for model year 2008 light trucks. CAFE-CEMS is also able to conduct analysis of passenger cars.

My comments are based on the CAFE-CEMS model documentation, draft 5/4/05, accompanying input spreadsheets (demo_marketdata_042805, demo_parameters_042805, demo_scenarios_042805, demo_technologies_042805), associated output spreadsheets, and occasional electronic communications from Carol Hammel-Smith (NHTSA) clarifying CAFE-CEMS's state of development. I have not examined the implementation of CAFE-CEMS's algorithms and logic in the computer source code.

Given its specific and broad objectives, the CAFE-CEMS model necessarily incorporates data and assumptions about technologies, economic analysis, energy use and emissions of the light-duty vehicle sector. In general, CAFE-CEMS's applied economic modeling and assumptions appear reasonable for its intended purposes. Lack of complete precision in the model documentation creates some ambiguity for interpretation. I indicate below general and specific suggestions for improvement of CAFE-CEMS and its documentation. I also list a number of questions.

One area that should be further addressed is technology cost and fuel use uncertainty. CAFE-CEMS appropriately incorporates the range of fuel savings and technology costs from the NRC's CAFE report by using low, average and high parameter estimates. For any given model run these are set from the options menu. For example, the user could select low technology costs and high fuel use. The model is then run and technologies are chosen according to the algorithms in the model and the resultant model outputs are produced. What would be superior is an automated process that picks from, perhaps, two independent, uniform probability distributions of technology cost and fuel consumption estimates. This could be done for all or a sub-set of the parameters. If CAFE-CEMS were then run repeatedly, perhaps several hundred to one-thousand times, this would produce a much fuller range of interactions of technology cost and performance. This process would highlight which input assumptions are the most important for the model's chosen technologies and resultant outputs. Additional work could then be focused on reducing the uncertainty in those highlighted input assumptions. This addition would enhance the robustness CAFE-CEMS's predictions of technology adoption and resultant fuel consumption, energy use, emissions and other impacts.

Specific Comments
Compliance Simulation and Technology Application

1. Please comment on the "engineering conditions" that we employed (Table 3 in documentation) to constrain the applicability of various technologies. My comments refer to Table 4.

A. Strict engineering assessments are not my strength as a reviewer.

2. Please review and comment on the logic (Figure 3, Figure 4, and surrounding text in documentation) we have developed to simulate the application of technologies in response to CAFE standards.

A. The logic developed to simulate the application of technologies to each vehicle model, engine, and transmission (as described in the text and shown in Figures 3 and 4) appears appropriate and reasonable. At times, nonetheless, the logic is difficult to follow. I describe this ambiguity in more detail below.

B. The logic of CAFE-CEMS is difficult to follow in places. It would help for a more detailed statement of CAFE-CEMS's equations with precise use of subscripts indicating sets and subsets. In particular from the text and general equations, CAFE-CEMS's primary objective is, for each manufacturer, *F*, to minimize the discounted sum of effective costs, cafe fines, credit sales/purchases and technology costs. This should be written out in full. For manufacturer *F*, this would look something like this:

$$Minimize \quad OBJ_F = \sum_{t=1}^{t=T} \sum_j \frac{1}{(1+r)^t} \sum_i \left(\frac{\Delta TECHCOST_j + \Delta FINE_i - VALUE_{FUEL_j}}{Nj} \right) N_i \quad (1.1)$$

Where:

$$Fine = -k_F\,[.], \quad (1.2)$$

For example, consider Equation 1.1 in the documentation:

$$Cost_{eff} = \left(\frac{\Delta TECHCOST + \Delta FINE - VALUE_{FUEL}}{Nj} \right). \quad (1.3)$$

In the text, we are told that $\Delta FINE$ is defined (appropriately so) only for a subset of *j* of all vehicles *i* that could use technology *k*. Thus, a clearer statement for evaluating technology *k* equation 1.1 is:

$$Cost_{eff,i} = \left(\frac{\Delta TECHCOST_j + \Delta FINE_i - VALUE_{FUEL_j}}{Nj} \right) \quad \forall\, k \in i. \qquad (1.4)$$

C. Secondly, it would also be helpful if there were a new table listing all variables, set definitions and symbols used throughout the documentation. A couple of cases highlight the issue. On p. 16, l. 16, we see language "vehicle i," where as on p. 16, l. 24 we see "model i." Are model and vehicle the same thing? Additionally, p. 16. l. 25 we see *v* used to indicate an incremental year to model year MV, but on p. 20, l. 28, we see *t* used to increment MV. Are *t* and *v* the same index?

A table like this would be helpful.

Name	Definition	Range/subset	Units
i	Model	$i \subseteq j$	
j	cohort class	$j \in J$	
$Cost_{eff}$	effective cost of new technology		$/vehicle
$Credit_c$	CAFE credits		vehicles *m/g
Etc.			

D. Figures 3 & 4. How do Figures 3 and 4 interact? Is Figure 3 nested in Figure 4 or the reverse?

E. In equation 1.2 I don't understand the rationale for adding 0.5 to v in the discount term $\frac{1}{(1+r)^{v+0.5}}$. This needs to be justified or modified.

F. It is unclear to me how the application of Best Next technologies interacts with potential vehicle sales mix changes as an alternative compliance strategy.

G. As an alternative modeling approach to the one used here, the logical test at the top of Figure 3 could be to minimize $COST_{eff}$ rather than Fines Required. This would allow for a later expansion of CAFE-CEMS to allow for across manufacturer credit trading. The logical test of Fines Compliance and willingness to pay fines would come after a manufacturer applies the Best Next technology that is cost effective.

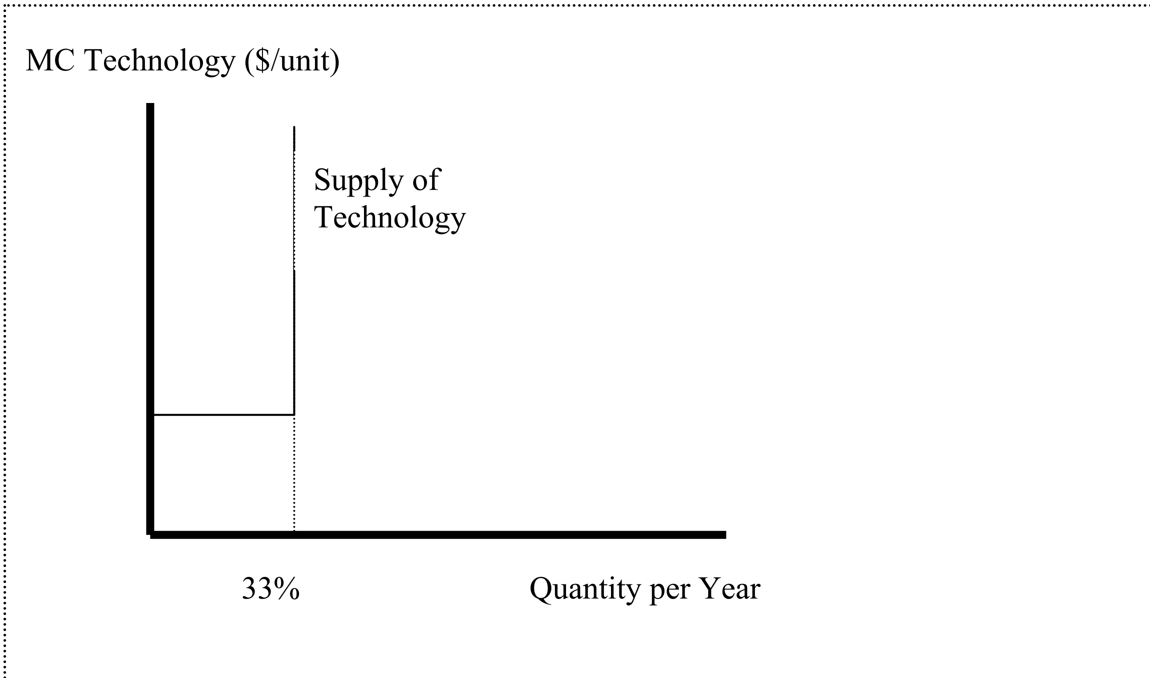
H. Figure 4. Determination of …Applications. There appears to be a logical error in decision box: "Can pending technologies still be applied to some vehicles?" There are two paths to enter this test, but there is only one exit: "yes", which then evaluates potential applications of pending technologies. It would seem that this decision box should have a "no" choice.

I.   Figures 3 & 4. I am concerned about possibility for the non-minimization of costs and non-optimal technology choice arising from path dependency in the solution algorithm. The text (p. 19) after Figure 4 states: “Within a given technology group, the algorithm considers technologies in the order in which they appear.” It appears from Figure 3 that one could find that the most cost effective technology would be from, for example, the Accessory Load Reduction set. This would then be applied; next a technology from Transmission Modification would be best, and so on. However, it might be true, that an alternative path would yield lower costs when considered as a whole. What steps have CAFE-CEMS’s developers taken to guard against this possibility? Has the order of technologies in each technology group been arranged to prevent this? Is there a way to explore alternative paths via slight changes in technologies’ costs or applicability assumptions? Given the number of technologies (and the cheapness of computing power) a global search algorithm that examined all feasible combinations of technologies may be tractable.

J.   P. 20, eq. 1.14 Although it may work, it seems a bit awkward to define *new* vehicles of model *k* produced in model year *MY* as $n_{k,MY}$ and then define the number of vehicles of model k produced in MY still surviving in year future year t as $n_{k,MY,t.}$ A cleaner way to define both concepts is to use $n_{k,MY,t}$ with the convention that for new vehicles t=0 or 1 (as per footnote 33).

3. Please review and comment on our input assumptions (Table C-5 and similar) regarding the applicability, cost, and effectiveness of different technologies.

A. CAFE-CEMS’s authors have chosen a practical way to address the very important and difficult issue of how to constrain the introduction of the rate at which new technologies can penetrate the fleet. In particular they have chosen to model the supply curve as horizontal (constant unit costs) with a vertical kink or limit. The example below shows the kink with a 33% phase in limit.



This is a reasonable approximation given that the limits are correctly set. I am unable to comment on the engineering considerations concerning the specific limits employed in CAFE-CEMS.

Ideally, CAFE-CEMS would allow greater levels of penetration per year at an increased (i.e., non-constant) cost per unit. This would reflect such real-world considerations such as having to pay overtime to run assembly plants at more intense levels or earlier retirement and replacement of capital equipment. Benchmarking upward-sloping technology cost curves, and accounting for a more rapid turnover in capital equipment, may or may not be feasible depending on the availability of data at the manufacturing plant level.

4. Have we thoroughly represented specific technologies? Have we omitted technologies that we should include, or are there others currently included that we should omit? If additional technologies are suggested, what input assumptions should we make regarding applicability, cost, and effectiveness, and what "engineering constraints" should we apply? (pp. C9-C11)

A. CAFE-CEMS has chosen to allow for dieselization. I am concerned that this technology may not be available for use in states certifying to California Air Emission standards.

Cost Allocation

5. Please review and comment on the cost allocation strategies employed. Have we omitted any cost allocation strategies that should be included? (Section II.B.2)?

A. The cost allocation strategy employed in this version of CAFE-CEMS is set at the default "as incurred".

Effects Calculations

6. The system currently employs vehicle survival and mileage accumulation schedules developed by EPA for use in its MOBILE6 vehicle emission factor model (see Appendix C, Table C-17 and surrounding text), and these values vary significantly among different types of vehicles at each age during their expected lifetimes. Are these vehicle survival and use assumptions the most appropriate to employ in analyzing various effects of stricter CAFE standards, or is more reliable information available?

A. On 31 May 05 Carol Hammel-Smith (NHTSA) indicated that the MOBILE6 data have been replaced by similar schedules estimated from odometer-based estimates of annual mileage from the 2001 National Household Transportation Survey. Survival rates used in the model are estimated from R.L. Polk's National Vehicle Population Profile for 1997-2002. These data sources are appropriate.

7. We currently account for the difference between laboratory and on-road fuel economy using a single estimate of on-road mileage shortfall for all vehicle classes and fuel types (Appendix C, p. C26). Should we attempt to identify estimates of this difference that vary among vehicle types or technologies? If not, what adjustment(s) to the current value would be appropriate to apply for vehicles to be sold during model years 2008-2012? (equations 1.2, 1.20, 1.37, Table C- 14)

A. The 15% fuel economy factor presumably comes from study: Hellman, K.H. and J.D. Murrell. 1984. "Development of Adjustment Factors for the EPA City and Highway MPG Values," SAE Technical Paper Series #840496, Society of Automotive Engineers, Warrendale, Pennsylvania. Given that this is somewhat dated, a newer adjustment factor may be appropriate.

B. I note that the "forecast data" spreadsheet for benefit computations uses the on-Road to EPA test MPG ratio of 0.752 (cars) and .820 (trucks). The AEO2005 is given as the reference. This inconsistency should be addressed; the same ratio should be used in both parts of CAFE-CEMS.

8. Please comment on the appropriateness of our input assumptions regarding the following social costs of fuel production and driving: petroleum market externalities, congestion, noise, and accidents. Please identify any estimates of these costs that you feel would be more appropriate to use in assessing the economic benefits from reducing fuel production and use or the economic costs of additional driving. (pp. C27 - C29).

A. CAFE-CEMS generally uses appropriate, mid-range estimates of the social costs of driving as found in the published literature. This includes parameters from the GREET model, MOBILE6, and work by Green, Leiby, and others.

B. P. 26. Why does CAFE-CEMS reduce carbon emission saved by only accounting for fuel refined domestically via the parameter, r? This seems inconsistent with the treatment of carbon emissions from petroleum extraction which ignores the source, domestic or foreign, of the crude oil.

C. P. 27. CAFE-CEMS calculates the increase in criteria emissions from the rebound effect correctly noting that criteria emissions are regulated on a per-mile, as opposed to a per-gallon basis. To the extent that the relationship between fuel use and criteria emissions becomes stronger for mileage greater than emission certification requirements, decreases in fuel use may decrease criteria emissions for high mileage vehicles. Should this offsetting effect be taken into account?

D. A minor point, but one that could help for updating CAFE-CEMS is one of units and conversions. The text notes (p. C-24) that the monopsony cost of oil imports comes from a 1997 study by Leiby et al. A mid-point range for this cost is given as $2.50/barrel. The text and spreadsheet note that this is approximately $0.061 gallon. Simply performing this calculation yields a slightly different answer, $2.50/42 = $0.0595. Similarly, the text also uses a price shock component at $2.00/barrel and states this is equivalent to $0.045 a gallon. Again, performing the calculation yields a slightly different answer, $2.00/42 = $0.0476 gallon.

Another example is given by the discrepancy in the base year dollar convention. Table C-21, "Forecast Data" notes that retail fuel prices are in 2001 dollars, while the "Economic Values" spreadsheet states that prices are in 2003 dollars. Given the current low rates of inflation this is not a serious problem.

My point is to not to identify minor errors of no appreciable importance to CAFE-CEMS's overall results, but to insure consistency and transparency. It might be preferable to create a new spreadsheet with all the primary data in the original units (and dates) and then show, explicitly, in the spreadsheet how the conversions are performed. This may facilitate updating CAFE-CEMS through time and increase overall transparency and accuracy.

E. I may have missed it, but I did not see a discussion of the renewable fuel (e.g., ethanol) content assumption for gasoline. It would seem reasonable to add some additional capacity to CAFE-CEMS to examine the energy and environmental impacts from implementing a national renewable content standard as has been proposed in recent legislation.

Specific Additional Comments

1. p. 2, l. 17. There is small grammar error, “tight the deadlines” should be “the tight deadlines.”
2. p.2, l. 19. Is “set no *more* than 18 months” correct or should the statement be, “set no *less* than 18 months?”

Review #2

The CAFE compliance and effect model developed by the Volpe Center for NHTSA could serve as a useful tool to automatically evaluate costs and benefits of potential CAFE requirements for light-duty vehicles. The automation of the CAFE evaluation process will enable users to simulate in an interactive way effects of potential ways of meeting a new CAFE requirement by manufacturers.

General Comments

1. As to be the case for any other computer models, the results of the CAFE model, in terms of costs and benefits of potential CAFE requirements, rely heavily on input parameters in the model. As of now, key technical input parameters in the model are from the 2002 NAS study. Though comprehensive, the NAS study has its limitations. For example, hybrid electric vehicles were not addressed in that study. In addition to the NAS study, a study sponsored by the NESCAF has evaluated technological potentials and costs of various vehicle technologies for California's GHG emission regulations. The results from that study may serve as a valuable supplement to the 2002 NAS study for the CAFE model.

   Besides relying on results of completed studies, NHTSA needs to make efforts to address costs and technological potentials of additional fuel efficiency improving vehicle technologies. Such efforts need to be made periodically to reflect emerging technologies. The efforts should engage manufacturers and other agencies.

2. The CAFE model is supposed to predict benefits and costs of potential future CAFE requirements. The demo version of the model contains historical data for some of the key parameters (such as available vehicle models and their sales). It was not explained how such data for future years would be obtained for simulations of future years.

3. p.6, Lines 17-18. "…detailed confidential product plans provided by some manufacturers with "synthesized forecasts of other manufacturers' offerings." Usually, manufacturers treat such information highly confidential. If such information is provided to NHTSA on a voluntary basis and only by some manufacturers, I wonder how NHTSA ensures the reliability and completeness of such information.

4. p.7, Lines 1-7. The CAFE model relies on EPA's Mobile model for generating vehicle operation-related emissions. EPA's LDV Tier 2 emission regulation specifies seven bins among which a manufacturer can select for emission compliance by given vehicle models, as long as the fleet average NOx

emission standard of 0.07 g/mi. is met by the manufacturer. To accurately estimate changes in criteria pollutant emissions, NHTSA needs to know which individual models will meet which bin standards so that emission changes can be simulated from the changes in vehicle model mixes caused by meeting CAFE standards. It appears that this is not the approach that is taken in the current version of the CAFE model. In fact, later in the report, it is shown that vehicle operation emissions are estimated for passenger cars and a few LDT classes without getting into the level of individual bins. This is troublesome, especially if hybrids and AFV technologies are to be considered for meeting CAFE standards by manufacturers. Experience in the past several years indicates that manufacturers may certify advanced technology vehicles to lower bins. It seems necessary that bin-specific emissions need to be estimated with Mobile and decisions need to be made on which vehicle technologies (or ideally which vehicle models) will meet which Tier 2 bins so that changes in criteria pollutant emissions can be accurately simulated.

5. Default Mobile simulations generate calendar year specific emissions for existing on-road vehicle fleets. Simulation of emission effects of meeting CAFE requirements by the CAFE model seems to require emissions for a given model-year vehicle type over its entire lifetime, which can be generated with Mobile. This approach may need to be used in the CAFE model.

6. Though hybrid technologies are included in the CAFE model, it is not clear how hybrids are to be simulated in the model. In particular, are they going to be simulated at subsystem levels (such as powertrain, engine, motor, battery, etc.), or at an aggregate level (such as mild and full hybrids)? Ideally, hybrids may be simulated at the subsystem levels so that effects of hybrid component technologies can be analyzed. But this may require use of some detailed vehicle models such as PSAT and ADVISOR.

7. The current version of the CAFE model is designed with intensive data requirements. Users seem to be regulatory agencies such as NHTSA and EPA who may have access to such detailed data. If the model is also to be used by others who have less access to detailed data, some compromise between accuracy of simulations and intensiveness of data requirements may have to be made.

Specific Comments

p.3, lines 3-4. Even though it is stated that the model will allow for an uncertainty analysis to generate the potential range of outcomes, I did not see this feature in the current version. Is this a task that the next version of the model will address?

p.4, Table 1. It is noted that AFVs are not included in the CAFE model. Yet there are more than four million ethanol FFVs which have been produced by automakers and which earned CAFE credits. To effectively model CAFE credits of FFVs and other vehicle technologies and their impacts on overall CAFE compliance (and furthermore the potential effects on reduction of US transportation oil use), it seems necessary to include AFVs in the model.

p.5, Lines 24-26. Although Mobile is currently used for estimating vehicle emissions, EPA has been working on developing a new generation of vehicle emission model (called MOVES). MOVES will be very different from Mobile in terms of architecture and results. NHTSA needs to pay attention to this EPA effort so that MOVES can be used for the CAFE model as soon as EPA makes it official.

p.5, Lines 35-38. If AFVs are to be included in a future version of the CAFE model, it seems desirable that some of the features in the TAFV model that was developed at Oak Ridge National Laboratory could be incorporated in the CAFE model.

p.5. In discussion of available models, the PSAT model is missing. The PSAT model was developed at Argonne to simulate fuel economy of different vehicle technologies under different driving conditions and for different vehicle performance requirements. It is required for use by the USCAR and DOE's FreedomCar program to simulate advanced vehicle technologies for the partnership between USCAR and DOE.

p.6, Line 12. The term "nonpassenger automobile" is used frequently in this report. Please give some examples of nonpassenger automobiles.

p.10, Lines 20-22. Are the vehicle classes used in the CAFE model consistent with the classes in EPA's annual fuel economy trend reports? It is critical to maintain some consistency so that EPA-collected fuel economy information can be used in the CAFE model.

p.11, Table 3 and Line 13. Many readers may not be familiar with the three technology paths specified in the 2002 NAS study. Please explain the three paths in the report.

p.16, Lines 25-27 and Footnote 16. It seems that the CAFE model calculates private cost savings of increased fuel economy from consumers' point of view. On the other hand, the model considers social benefits in dollars from reductions in emissions and imported oil. How does the model reconcile the two types of monetary benefits eventually?

p.20, Line 23. I did not see equations 1.6, 1.7, and 1.8.

p.20, Footnote 31. Discussion is needed on whether emissions should be discounted or not.

p.25, Lines 6-8. "the increase in vehicle use that results from improving their fuel economy via the rebound effect will raise emissions of these pollutants." This statement is not true for tailpipe SOx emissions and evaporative VOC emissions. The reductions for these two emission sources that result from fuel use reduction could far exceed the potential increase in them from the rebound effect.

p.25, Equation 1.27. Please note that g is fuel consumption in gallons. Also, please note that fuel-specific carbon content for gasoline may vary over time because gasoline mix (conventional vs. reformulated) may change over time.

p.26, Equation 1.29. $r \cdot c_r$ needs to be separated for feedstock and fuel stages for gasoline and diesel because domestic production shares are so different for petroleum (feedstock) and fuels (i.e., gasoline and diesel).

p.26. When other fuels such as ethanol and CNG are to be included in a new version of the CAFE model, emissions of producing these fuels will need to be included in the new version.

p.27, Equations 1.31 and 1.32. It seems the minus sign should be plus sign.

p.27, Lines 14-16. Mobile generates emissions for general vehicle classes such as passenger cars, LDT1, LDT2, etc. It does not generate emissions for the vehicle classes contained in the CAFE model (cars, small SUV, large SUV, small truck, large truck, etc.). Furthermore, in order to accurately predict emission changes from vehicle model mix changes caused by CAFE compliance, vehicle model-specific emissions may need to be generated (see a previous comment).

p.27, Footnote 39. For emissions with the U.S. context, the CAFE model may need to separate foreign and domestic emissions so that foreign carbon emissions may not be included in CAFE modeling.

p.27, Lines 30-33. Again, petroleum and its fuels (gasoline and diesel) need to be separated for emission calculations (see an above comment).

p.28, Equation 1.34. $e_{i,k,MY,t}$ could be different among CAFE scenarios because of potential changes in vehicle model mixes caused by CAFE compliance.

p.28, SOx emissions can be calculated in a way similar to the calculation for CO2 emissions. That is, SOx emissions can be calculated by assuming all sulfur in a fuel is converted into SO2 emissions.

p.29, Lines 8-9. A better subtitle format is needed so that these two can be differentiated.

p.29, Line 21. "high prices result in losses in welfare or consumer surplus to buyers…" This effect may be tiny.

p.29, Lines 36-41. Please note here that a payback period of 5 years and a discount rate of 7% are used in the CAFE model.

p.29, Lines 45-46. "The rebound effect results in additional benefits to new vehicle buyers in the form of consumer surplus…" This effect could be tiny.

p.30, Lines 10-11. Use of one half of the product of the decline in fuel cost per mile driven in vehicle models with increased fuel economy and the resulting increase in the annual number of miles they are driven seems to be a very crude assumption.

p.30, Footnote 42. It appears that there is some evidence that this is the case.

p.31, Lines 13-14. "The pre-tax price per gallon is used in assessing the value of fuel savings to the economy as a whole." It is questionable to assume that the pre-tax price of a fuel reflect the social cost of the fuel.

p.32, Lines 25. "…although this influence appears to be limited." The recent oil price increases appear to show that even small increase in oil import by countries (such as China and India) could have a significant psychological and materialized impact on world oil price.

p.35, Lines 6-7. "using estimates of the value per ton of emissions of each pollutant that is eliminated." Dollar values of air pollutants could vary significantly among different US regions.

p.36, How about the concern that CAFE may result in less safe vehicles and resultant increased social costs?

p.B-3, Lines 8-11. I did not see that feature when I ran the CAFE model.

p.B-4. Help functions are needed to explain the three technology paths (see an above comment).

p.C-1. For the parameter group, I have the following comments. First, fuel properties seem to be from GREET1.5, which need to be revised with the most recent GREET version. Second, I wonder if the US imports 26.4% of its gasoline and diesel from other countries. I remember that gasoline and diesel imports are usually small for the US. Third, the crude import share in the model is questionable. Fourth, upstream emissions for fuels need to be updated with the new GREET version. Fifth, tailpipe SOx emissions can be calculated with sulfur content of gasoline and diesel (see a previous comment).

In general, the above parameters could be changed over time. Maybe time-series tables can be designed in the CAFE model for these parameters to address this issue.

p.C-2, Line 4 and Table C-2, I only saw year 2002 in the model.

p.C-11, Lines 18-19. "a 35% reduction in the rate of fuel consumption." This reduction seems to be volumetric based fuel consumption. It is better to refer to Btu-based fuel use reductions.

p.C-20, Table C-16, Lines 10-24. The data sources in the table and in the two paragraphs followed are contradicting with each other. Please clarify the actual data source used for vehicle age data.

p.C-21, Table C-17. Fuel properties need to be updated with the current GREET model.

p.C-22, Table C-18. Upstream emissions in GREET are in grams per million Btu in lower heating values for fuels. On the other hand, EIA uses higher heating values in its statistics. Please make Btu values consistent within the CAFE model when using data from different sources.

p.C-25, Lines 20-23. It is not a good reason that CO2 dollar values are not included because there is a wide range of dollar values per ton of CO2. The same can be said to dollar values for criteria pollutants. Yet, monetary values for criteria pollutant emissions are included in the model.

p.C-26, Table C-21. The unit for automobile and light truck ratios (expressed in double) seems not correct.

p.D-1, Footnote 76. It appears that the baseline scenario has a cost of $2 billion. Please clarify.

p.D-7, Table D-8 (and other similar tables). The values in all parentheses are supposed to mean negative values. Please change Excel cell format to reflect this.

Review #3

July 29, 2005

Ms. Carol Hammel-Smith
Fuel Economy Division
National Highway Traffic Safety Administration
Room 5320
400 7th Street
Washington, DC 20590

Re: Peer Review of CAFE Compliance and Effects Modeling System (Final)

Dear Ms. Hammel-Smith,

This document represents the final letter report associated with my review of the CAFE Compliance and Effects Modeling System which is being developed by NHTSA with technical support from the Volpe National Transportation System Center.

In accordance with the contracted Statement of Work, the purpose of the review was to highlight potential changes in methods, data and assumptions that could enhance the model. We were further requested to evaluate the extent to which methodological changes could yield better results and likewise, to what extent changes to data and process assumptions might improve the analyses.

I wish to compliment the NHTSA staff on the efforts that have been conducted, to date, in preparing the code and the responsiveness in answering all technical questions posed. However, based upon my review of the technical approach, there are fundamental assumptions behind the National Academy of Science (NAS) report on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards that severely limit their applicability to the process being considered under the NHTSA model.

Accordingly, significant and perhaps unacceptable errors will likely result when applying the NAS incremental technology fuel economy improvement estimations to individual manufacturer vehicles.

The NAS estimations were developed as “Class-Averaged Estimates” in which variations across manufacturers and vehicle types were “averaged out” over a large distribution of vehicles. However, the assessment of potential fuel consumption improvements on individual vehicles requires, in my opinion, significant engineering assessment and engine, powertrain and full vehicle modeling that was not conducted by the NAS committee.

In the discussion below, I will attempt to provide some additional background information and further discussion of my concerns and recommendations.

Background

As you are aware, I was a member of the NAS Committee on the Effectiveness of Corporate Average Fuel Economy (CAFE) Standards, whose final report was released by the National Research Council in January 2002. Within our report, we concluded that "technologies exist that, if applied to passenger cars and light trucks, could significantly reduce fuel consumption within15 years."

The committee was charged with reviewing the effectiveness and impact of existing CAFE standards and providing recommendations for future consideration. During the course of our review, the committee desired a practical method by which potential improvements in fuel economy could be estimated when considering the application of current and advanced technologies to vehicles sold in the U.S. An approximation methodology was developed, as described in the NAS report, which you have accurately documented and utilized in your code.

However, the approach was intended as, and is limited to, a way of providing the Committee with estimates of what might be possible within a class of vehicles. Accordingly, by a class, we considered an entire vehicle class which is represented by a distribution of vehicles across a variety of manufacturers. Stated another way, a hypothetical vehicle was defined with characteristics that were derived from sales-weighted averages of all vehicles sold within a particular vehicle class. This hypothetical vehicle was considered representative of the class and a starting point for estimating potential fuel consumption improvements.

Under this assumption, we believed that general estimations were possible of what might be accomplished when looking at a class as a whole. These assumptions required significant engineering judgment which was provided by qualified members of the committee under the constraints of the committee resources and timetable. However it is my opinion that one cannot simply apply this approach to any individual vehicle and get an accurate prediction of improvements in fuel consumption.

The method necessary to more accurately estimate potential improvements in fuel consumption of individual vehicles requires detailed engine, transmission and vehicle performance maps, transient data, calibration information, transmission shift points, and a whole host of other data that vehicle manufacturers consider proprietary. As discussed in the CAFE Committee proceedings, this would require thousands of engine and vehicle simulations that still rely on assumptions, proprietary data and must be calibrated against experimental data before significant conclusions can be drawn. Although theoretically possible, it is my opinion that such an effort is not feasible and would still require proprietary data which is only known to the individual manufacturers.

It is this concern that causes me to suggest that the approach you have outlined in your code is an inappropriate use of the NAS data. Furthermore, due to the approximate nature of our estimates and the compounding error that occurs as an increasing number of technologies are added, we stated in the CAFE report that our fuel consumption analyses and the break-even cost analyses cannot and should not be used to recommend fuel economy goals. Using the same data in an attempt to estimate the potential approaches an individual manufacturer would use to comply with future standards is equally flawed, in my opinion.

Technical Discussion

As part of our vehicle class analysis, we attempted to identify a theoretical or hypothetical vehicle which was defined by assessing a sales-weighted average for vehicle characteristics and technology features within a class. For example, if the number of engine cylinders was determined to be 7.5 per vehicle sold (a sales-weighted average between 8, 6 and perhaps 5 or 4), then we assumed that the class-representative vehicle had an 8 cylinder engine. If the result was 6.4 cylinders per vehicle, we would then assume a 6-cylinder engine as class representative.

This process was followed for all major engine, transmission and other vehicle characteristics, such as vehicle weight. This approach allowed us to determine a representative vehicle from which to begin the engineering judgmental process of applying technology “paths” that the members of the committee deemed possible for different types of vehicles. For instance, the application of cylinder deactivation to 4-cylinder engines is theoretically possible, but the resulting roughness of the powertrain is potentially unacceptable. It was this type of judgment that was used in our approach. However, the class-representative vehicle is hypothetical and is not representative of any one vehicle in the class.

Another very important technical issue is the potential for compounding error and the possibility of approaching or exceeding theoretical limits for benefits that can be realized as additional technologies are subsequently applied. During the course of the CAFE proceedings, we assessed the potential improvement in fuel consumption in the form of ranges, both in potential improvement and the associated cost increase. Accumulation of these ranges with an increasing number of technologies will become very large, as we identified in the CAFE report. Again, on a class-averaged basis, we accepted averaged values as representative. However, when one evaluates individual vehicles, such ranges would need to be reduced through much more detailed analyses than we conducted, in order to draw meaningful conclusions.

An equally important range-related factor is the associated incremental cost. Early in the public comment period, it became apparent that the use of cost ranges could be skewed toward desired results. Certain parties attempted to argue that significant fuel economy gains were possible with very little cost increase.

Likewise, others argued that very little improvement would be achieved at significant cost.

The problem is that they can both be correct, or incorrect, depending upon the individual vehicle boundary conditions, the age of vehicle, where the powertrain systems are in their development, plant depreciation cycles, and so on. Therefore, again we believed that on a class-averaged basis, approximate values for fuel consumption improvement and cost were reasonable. However, they are likely erroneous on an individual vehicle and manufacturer-specific basis.

Also, as additional technological improvements are incrementally considered, it is important to assess the limitations in reducing losses, for instance in reducing friction, pumping (gas exchange) losses, aerodynamics, etc. This can result in so-called “double dipping” which was the subject of quite some debate during the CAFE proceedings. Evaluating hypothetical, class-averaged vehicles reduces, but does not eliminate this potential error. However, on an individual vehicle basis, there is an increased likelihood of compounding error that could exceed practical and even theoretical limits. This is where the detailed engine, powertrain and vehicle simulation analyses, that rely on proprietary data are needed to reduce the likelihood of significant errors.

Response to SOW Questions

Several specific questions were listed in the Statement of Work (SOW) for which comment and answers were requested. Below please find my thoughts associated with each technology-related question.

Q1): *Please comment on the “engineering conditions” that we employed (Table 3 in documentation) to constrain the applicability of various technologies.*

It appears that the NHTSA computer model employs the technology assessment techniques of the NAS report, applies them to individual OEM vehicles within some assumed sales fleet and then predicts the ability to comply with a proposed CAFE scenario. The model weighs the cost of non-compliance fines against the predicted incremental cost of adding additional technology (production-intent or emerging) and balancing these potential scenarios for each vehicle model and manufacturer. The computer model then, apparently, considers the impact that this will potentially have on the marketplace.

As outlined in the Background section of this report, I have critical reservations about applying the technology versus cost parameters taken from the NAS CAFE report to individual vehicle models. The NAS report technique was based on identifying an “average hypothetical vehicle” for each vehicle class to determine engineering judgment-based “likely technology” (production-intent and emerging) that will be available over the next 15 years versus the estimated cost of that technology (in 2002 dollars). In my opinion, this approach cannot be transferred to a “vehicle model-specific” method, as used in this computer code.

Under the boundary conditions of the CAFE Committee, we attempted to identify likely technology scenarios for different classes of vehicles. These so-called “paths” relied on engineering judgment and some general knowledge of technology introductions. In some cases, technology introductions will not follow a cost benefit path, but may be related to the ease of implementation, even at higher unit cost, or perhaps marketing trends. Certainly, one can use the NHTSA code to evaluate “what-if” scenarios, but the accuracy of the predictions is questionable, becoming increasingly so as more technologies are accumulated.

Another technical issue and basis for concern, in my opinion, is the increasing difference between in-use fuel consumption and that which is measured in the EPA city, highway and combined cycles. As new technologies, such as idle-off, mild hybridization and diesel engines enter the fleet, differences between the certification and on-road results will likely increase.

If the primary purpose of the code is to evaluate the influence on compliance when evaluated under the EPA test cycles (keeping in mind the concerns expressed above), then certain conclusions could be drawn. However if the analysis chooses to evaluate actual fuel savings (in gallons) over the ownership or life of the vehicle, plus the influence on resale value, then more attention should be paid to these differences.

Q2). *Please review and comment on our logic (Figure 3, Figure 4) and surrounding text in documentation) we have developed to simulate the application of technologies in response to CAFE standards*.

I have commented extensively on my concern related to the applicability of applying the NAS incremental improvements on an individual vehicle basis. The following comments refer only to the logic shown in Figures 3 and 4.

The compliance simulation and “next-best” selection algorithm (Figures 3 and 4) may not predict the actual preferred or desired path taken by any individual manufacturer on any individual model (or models with the same powertrains) regardless of the CAFE scenario.

Under these logic algorithms, it is possible that the choice of the “next-best” technology could go in an improbable direction for individual manufacturers and/or vehicle models. For example, a particular manufacturer may choose a specific “next best” technology, such as “accessory-load reduction.” However, another manufacturer could skip this benefit and proceed with some other technology introduction because they plan a new engine design introduction for non-CAFE compliance reasons, perhaps driven by marketing input or performance enhancement. Another manufacturer may have a completely different set of boundary conditions leading to yet another preferred solution.

Therefore, although the NHTSA code may be used to evaluate possible scenarios, the ability to predict actual market-driven options is highly questionable.

Q3). *Please review and comment on our input assumptions (Table C-5 and similar) regarding the applicability, cost, and effectiveness of different technologies*.

The "Technology Input" files, (table C-5) appear similar to the NAS report tables with the addition of material substitution options, dieselization and the addition of a midrange hybrid. In conversations with NHTSA technical staff, I understand that there are some potential differences in the values from those included in the CAFE Committee report, based upon updated published information and input from manufacturers. There also appear to be three (3) additional columns in the file: "year available", "phase-in" and "kWeight".

"*Year-Available*": The "year available" column is apparently intended to determine the year in which the technology is available for application in production vehicles. It appears that the assumption is that all manufacturers will have the technology available at the same time.

This assumption may not be correct, depending upon the ease of applicability of certain technologies to existing architectures, such as cylinder deactivation. However, we further understand that it is possible to "override" the availability of a technology (in the "Vehicle Models Worksheet", "Engines Input Worksheet" or the "Transmission Worksheet") to compensate for these factors, as a precondition for the chosen scenario.

"*Phase-In*": A further change from the technology assessment made by the CAFE Committee is the "phase-in". This appears to be a correction factor for the likelihood that, once a new technology becomes available, manufacturers will be limited in their ability to integrate the new technology into existing vehicles. Therefore, a percentage "phase-in" is included to show the "uptake" rate of the technology. This is an attractive feature, when combined with the corrected year-available in which technology integration boundary conditions are considered. However, it requires significant knowledge of market conditions and may be difficult to predict

"*kWeight*": The CAFE Committee assumed that, initially, due to additional safety requirements, the vehicle weight would increase by 5%. This was included in the estimates for fuel consumption. Later in the technology matrix, it was assumed that material substitution could occur, thereby removing the 5% weight penalty. Accordingly, only one weight reduction scenario was considered. The NHTSA code has apparently assumed that there could be four (4) different weight changes: three (3) reductions and one (1) increase.

Q4). *Have we thoroughly represented specific technologies? Have we omitted technologies that we should include, or are there others currently included that we should omit? If additional technologies are suggested, what input assumptions should we make regarding applicability, cost, and effectiveness, and what "engineering constraints" should we apply? (pp. C9-C11)*

The addition of "dieselization" and "hybridization" technologies, which were referenced in the CAFE Report but not included in the technology options, is quite appropriate at this time. They represent somewhat expensive options, but with the increasing price of fuel and a growing national recognition of the importance of fuel economy, their expanding use is highly likely.

However, the inclusion of these technologies will further exacerbate the error in the NHTSA assumption that a vehicle's fuel economy is constant with respect to both age and accumulated mileage, and that the test versus on-road fuel economy gap is identical for all vehicle types and ages. There has been significant press given to the issue of EPA test cycle versus real-world experience in hybrid vehicles. However, as more technologies are introduced which address different kinds of efficiency loss in the vehicle, there is increasing likelihood that this mileage gap will continue to widen.

There is also significant evidence that the fuel consumption improvement through the application of advanced diesel technology increases with heavier vehicles. These factors should likely be considered in any future analyses to help offset the expected production cost trade-offs.

Recommendations

Although I cannot support the use of the CAFE Committee incremental technology improvements on individual vehicles, I believe that the NHTSA code can be used for several important functions.

First, it provides a very valuable and easy-to-use tool to assess potential trends in technology introduction and what the *class-based fleet* would possibly demonstrate in potential improvements and associated costs. As such the code could be used to assist in interactive discussion with different manufacturers during the rule making process and used to solicit input from the OEM's on a vehicle model-specific basis.

Second, I believe that the code can be used to evaluate strategies that individual manufacturers are following as they introduce new technology. Over time, NHTSA could potentially gain a better understanding of the particular technologies that different manufacturers are pursuing and what their relative gains have been, based upon careful tracking and assessment of technology introductions and the associated vehicle characteristics which result. However, I do not believe that the code could be used to predict future compliance scenarios with any reasonable degree of certainty.

Third, the code could be used to calibrate real-world fuel consumption improvements through a careful program of demonstration vehicles and fleet tests. In the end, the ultimate goal is to achieve a reduction in oil consumption and gauge the cost. The code would allow a mechanism to understand how different technologies influence in-use results and make recommendations on procedural directions. However, ultimately, proprietary vehicle manufacturer data may be necessary to fully understand these trends.

I wish to thank NHTSA for giving me the opportunity to review the CAFE Compliance and Effects Modeling System and I look forward to participating in the reviewers panel and file assessment report.