CAFE Compliance and Effects Modeling System

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I. Introduction

In December 1975, during the aftermath of the energy crisis created by the oil embargo of 1973-1974, Congress enacted the Energy Policy and Conservation Act (EPCA). The Act established an automotive fuel economy regulatory program by adding Title V, "Improving Automotive Efficiency," to the Motor Vehicle Information and Cost Saving Act. These corporate average fuel economy (CAFE) standards set a minimum performance requirement in terms of an average number of miles a vehicle travels per gallon of gasoline or diesel fuel. Section 32902(a) of Chapter 329 states that the Secretary of Transportation shall prescribe by regulation CAFE standards for light trucks for each model year in consideration of four factors in determining the "maximum feasible" fuel economy level:

(1) technological feasibility;
(2) economic practicability;
(3) the effect of other Federal motor vehicle standards on fuel economy; and
(4) the need of the Nation to conserve energy.

CAFE standards are set by statute for passenger cars and by regulation for light trucks. The first light truck CAFE standards were established for model year (MY) 1979 and applied to light trucks with Gross Vehicle Weight Ratings (GVWR) up to 6000 pounds. Beginning with MY 1980, NHTSA raised this GVWR ceiling to 8500 pounds. During the 1980's and early 1990's, light truck standards were set frequently, covering short time periods. In 1994, the agency departed from its usual past practice of considering light truck standards for one or two model years at a time and published an Advance Notice of Proposed Rulemaking (ANPRM) in the Federal Register outlining NHTSA's intention to set standards for some, or all, of MYs 1998-2006. On November 15, 1995, Congress put a freeze on all CAFE related activities in the Department of Transportation and Related Agencies Appropriations Act for FY 1996, stating:

> None of the funds in this Act shall be available to prepare, propose, or promulgate any regulations . . . prescribing corporate average fuel economy standards for automobiles . . . in any model year that differs from standards promulgated for such automobiles prior to enactment of this section.

In 1996, the agency set a light truck standard for model year 1998 at the existing 20.7 mile per gallon (mpg) level. The agency continued this practice due to the limitations on appropriations for model years 1999 through 2003.

The Department of Transportation and Related Agencies Appropriations Act for FY 2001 contained the restriction on CAFE rulemaking identical to that contained in prior appropriation acts. However, the conference committee report for that Act directed that NHTSA fund a study by the National Academy of Sciences (NAS) to evaluate the effectiveness and impacts of CAFE standards. NAS submitted its report to the Department of Transportation on July 30, 2001. The final report, released in January 2002, concluded that technologies exist that could significantly increase passenger car and light truck fuel economy within 15 years.

In a letter dated July 10, 2001, Secretary of Transportation Norman Mineta asked the House and Senate Appropriations Committees to lift the restriction on the agency's spending funds for the purposes of improving CAFE standards. The Appropriations Act for FY 2002, which was enacted on December 18, 2001, did not contain a provision restricting the Secretary's authority to prescribe fuel economy standards. Because the agency did not have adequate time to conduct an appropriate analysis, the MY 2004 CAFE standard was set at the existing 20.7 mpg. The following year, the agency set new CAFE standards for MY 2005-2007 that increased the standards for light trucks by a total of 1.5 mpg. The agency estimated the costs and benefits of this rulemaking using a combination of manual and automated technology analysis and spreadsheet-based effects analysis.

After the MY 2005-2007 light truck rulemaking ended, it became apparent that the development of an automated rulemaking tool capable of evaluating both the stringency and changes in the structure of the CAFE regulation would be desirable for a number of reasons. In the past, standards have been set by manually applying fuel saving technologies to individual vehicles to determine a standard. While this process has its merits, it is time consuming and generally not repeatable. An automated modeling system would help meet tight the deadlines demanded by the rulemaking process. Presently, we are limited to setting standards for only a few years at a time. CAFE standards must be set no more than 18 months in advance of the regulated MY. For example, standards governing MY 2008 must be set no later than April 1, 2006. If a standard is not set for a given MY, there is no CAFE standard for the year. The process begins at least a year earlier with a 90-day request for comment (RFC) and solicitation of manufacturer product plans. Once the data is analyzed, standards are proposed in a notice of proposed rulemaking (NPRM) followed by a 90-day comment period. Comments are analyzed and incorporated into the analysis to determine if there is a need to modify the proposed standards for the final rule.

Although the entire process takes a year or longer, the time allowed for analysis is much shorter. Initial standards must be determined after the RFC comment period has closed and before the NPRM is released. Final standards are determined after the NPRM comment period closes and before the FR is published. A computerized rulemaking analysis system would save time during the two short periods that the agency has to determine CAFE standards. Keeping the system updated in periods in between rulemakings would alleviate the need to "reinvent the wheel" every one, two or three years that CAFE standards must be set.

CAFE activities involve more than setting light truck stringency standards. The agency is frequently asked by Congress and the administration to evaluate alternative CAFE proposals that are considered in legislation. These requests must be answered within a few days. The agency is also involved in a rulemaking to reform the regulation. On December 29, 2003, NHTSA published an advanced notice of proposed rulemaking (ANPR) for CAFE reform. In the document, we describe potential reforms that we have the statutory authority to implement. Many of these reforms were suggested in the NAS report. In the past year, NHTSA had to evaluate a petition filed by Nissan of North America. All of these tasks will or would be greatly simplified by an automated rulemaking analysis system.

Over time, the analysis required to set CAFE standards has become increasingly complicated and presently includes a multitude of economic and environmental impacts that were not considered in the past. In addition to accounting for these impacts, a computer model will allow for the evaluation of incremental costs and benefits rather than total costs and benefits when setting standards. The model will also allow for an uncertainty analysis to measure the potential range of outcomes. Neither of these types of analyses are practical under the manual approach of applying technologies to each vehicle.

The CAFE rulemaking analysis system that is described in this document links all the analyses together into a cohesive and transparent computer model. The model can be used to analyze changes in CAFE stringency and the structure of the regulation separately or simultaneously over several model years. Given a policy change, the modeling system predicts how manufacturers will react through applications of fuel saving technologies to comply with CAFE standards. The system then determines the economic and environmental impacts that result.

When constructing the modeling system, we relied on well-known studies, models and assumptions from credible sources outside the Department of Transportation. Technology assumptions and implementation paths are taken from the National Academy of Science's CAFE report. Economic assumptions come from various academic publications and the Office of Management and Budget's regulatory guidelines. Environmental analyses are conducted using the Environmental Protection Agency's MOBILE6 model and Argonne National Laboratory's GREET model.

II. Comparability to Other Modeling Systems

Before beginning development of this modeling system, we considered other options for analyzing CAFE standards. However, such options are limited by structural and functional considerations. The most important structural requirement is the ability to represent the vehicle fleet in fine detail. Specifically, each vehicle model configuration, of which there are more than a thousand, must be accounted for separately. Important functional requirements include, but are not limited to the ability to properly account for various combinations of potential CAFE reforms, determine the applicability and cost efficiency of various technologies on a model-by-model basis, account for the use of a given engine or transmission across multiple vehicle models, calculate shifts in sales volumes resulting from changes in vehicle prices and fuel economy levels, properly assign vehicle models to relevant emissions "classes", and calculate changes in highway travel, energy demand, emissions, and economic externalities related to highway travel and energy consumption.

Although various other modeling systems address some of these requirements, and some do so more robustly than the system discussed here, we are aware of no other system that provides the ability to efficiently fulfill even a majority of these requirements.

The most relevant alternative modeling system known to us is the National Energy Modeling System (NEMS), which is maintained by the Department of Energy's (DOE's) Energy Information Agency (EIA).[1] NEMS is an integrated modeling system designed to forecast future energy supply and demand based on a wide range of data and assumptions regarding key supply

[1] NEMS documentation is available at http://www.eia.doe.gov/bookshelf/docs.html.

and demand sectors, and interactions with macroeconomic models maintained by Global Insight, Inc. With respect to CAFE, the following features of NEMS are especially relevant: explicit models of international petroleum markets, domestic petroleum production, and petroleum refining; representation of a wide range of technologies relevant to light vehicle fuel economy; explicit representation of CAFE standards for passenger and nonpassenger automobiles; and feedback between petroleum product price, demand, and supply. EIA uses NEMS to produce its Annual Energy Outlook (AEO) series and to respond to requests by members of Congress for analyses of potential policies, including potential CAFE standards.

We expect to use NEMS to develop some key inputs, such as fuel prices and domestic refinery output, for the system discussed here. Separately, because our system does not attempt to simulate energy supply, we also expect to use NEMS to examine potential feedbacks between CAFE policies and energy markets (although such feedbacks are typically estimated to be relatively small).

Table 1. Key Differences between this System and NEMS

Characteristic	This System	NEMS
accounting structure	model-by-model (1,000$^+$ records/year) with topic-specific aggregation	24 vehicle categories mapped to four groups (domestic and imported cars and light trucks)
CAFE policies represented	conventional standards changes to light truck definition expansion to cover heavy vehicles class-based standards CAFE credit trading (limited) function-based standards "fixed attribute" standards	conventional standards
intended modeling period	narrow (window of 3-5 model years)	medium (25 years)
technologies	"conventional" technologies HEVs	"conventional" technologies HEVs AFVs
technology cost estimates	static	dynamic
interactions with energy market	estimated using NEMS-based fuel price forecasts and other energy-related inputs	explicit feedbacks between energy consumption, supply, and prices
reporting	full useful life on MY-by-MY basis model-by-model manufacturer-specific industry-wide	annual on CY-by-CY basis import/domestic car/truck industry-wide

However, the ability of NEMS to meet the above-mentioned requirements is currently limited in several important ways, as is understandable given that NEMS is designed primarily for mid-term energy forecasting, not near-term regulatory analysis. Key differences, summarized above in Table 1, are as follows: First, and most important, although NEMS divides light vehicles into several representative classes, it cannot represent light vehicles on a model-by-model basis. This means, that NEMS does not produce manufacturer-specific estimates of compliance costs. Second, although NEMS allows for the year-by-year specification of standards for passenger and nonpassenger CAFE standards, it does not provide the ability to simulate most potential CAFE reforms. Because of its class-based representation of the vehicle market, modification of NEMS to represent many CAFE reforms would require significant data development and programming.

Among other modeling systems we have considered, key capabilities and limitations vis-à-vis analysis to support CAFE rulemakings are as follows:

ADVISOR: The "Advanced Vehicle Simulator" (ADVISOR), which was created by DOE's National Renewable Energy Laboratory (NREL) and recently commercialized by AVL Powertrain Engineering, estimates vehicular energy consumption through second-by-second simulation based on detailed vehicle and drive cycle characteristics.[2] Though possibly relevant in a vehicle design environment, ADVISOR's data requirements are far too extensive for CAFE analysis, and it provides no means of performing most other CAFE-related calculations (*e.g.*, compliance evaluation, cost estimation, fleet energy consumption and emissions). Similar vehicle simulation tools, such as AVL's CRUISE model and Argonne's PSAT model, share these basic capabilities and limitations.

GREET: Argonne's "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET) model is a spreadsheet-based system that estimates full fuel-cycle energy consumption and emissions for various combinations of vehicle technologies and fuels.[3] Although GREET does not perform other CAFE-related calculations (*e.g.*, cost estimation), we use it to estimate upstream (*i.e.*, non-vehicular) emissions as inputs to our modeling system.

MOBILE: EPA's MOBILE model predicts vehicular emission rates under various conditions.[4] Although MOBILE does not perform other CAFE-related calculations, we use it to estimate vehicular emissions as inputs to our modeling system.

SGM: Pacific Northwest National Laboratory's (PNNL's) "Second Generation Model" (SGM), developed as a complement to the PNNL's first generation model ("MiniCAM"), is a computable general equilibrium model with conceptual similarities to NEMS and explicit representation of transportation sector energy demand. However, the SGM does not explicitly represent CAFE standards, and its representation of the passenger vehicle market is far too generalized to meaningful for CAFE-related analysis.[5]

TAFV: Leiby and Rubin's "Transitional Alternative Fuels and Vehicles" (TAFV) model estimates the cost and consumption of alternative fuels and alternative fuel vehicles during a transition between a conventional market and a market in which such fuels and vehicles play a much more significant role.[6]

[2] Documentation of ADVISOR is available at http://www.ctts.nrel.gov/analysis/advisor.html.

[3] Documentation of GREET is available at http://www.transportation.anl.gov/software/GREET/index.html.

[4] Documentation of MOBILE (and a successor called MOVES that EPA is developing) is available at http://www.epa.gov/otaq/models.htm.

[5] Documentation of SGM and MiniCAM is available at http://www.globalchange.umd.edu/?tools.

[6] Documentation of TAFV is available at http://pzl1.ed.ornl.gov/altfuels.htm.

III. Design and Rationale

A. Overall Structure

The basic design of the CAFE Compliance and Effects Modeling System is as follows: The system first estimates how manufacturers might respond to a given CAFE scenario and then estimates what impact that response will have on energy consumption, emissions, and economic externalities. A CAFE scenario could involve one or more CAFE reforms, such as a change to the definition of nonpassenger automobiles, or a simple change in the stringency of either the passenger or nonpassenger automobile standard.

Compliance simulation and effects estimation encompass numerous subsidiary elements. Compliance simulation begins with a detailed initial forecast of the vehicle models offered for sale during the simulation period. In general, NHTSA and the Volpe Center assemble these forecasts by integrating detailed confidential product plans provided by some manufacturers with "synthesized" forecasts of other manufacturers' offerings.[7] The compliance simulation then attempts to bring each manufacturer into compliance with a CAFE policy scenario described in an input file developed by the user. The model sequentially applies various technologies to different vehicle models in each manufacturer's product line in order to make progress toward compliance with CAFE standards. Subject to a variety of user-controlled constraints, the model applies technologies based on their relative cost effectiveness, as determined by several input assumptions regarding the cost and effectiveness of each technology, the cost of CAFE-related civil penalties, and the value of avoided fuel expenses. For a given manufacturer, the compliance simulation algorithm applies technologies until the manufacturer achieves compliance, until the manufacturer exhausts all available technologies, or until paying fines becomes more cost effective than increasing vehicle fuel economy. The user may disable the fine paying option for manufacturers that generally do not pay fines, thus forcing the manufacturer to add additional technology. At this stage, the system assigns an incurred technology cost and updated fuel economy to each vehicle model, as well as any civil penalties incurred by each manufacturer.

This point marks the system's transition between compliance simulation and effects calculations. At the conclusion of the compliance simulation for a given model year, the system contains a new fleet of vehicles with new prices, sales levels, fuel types, fuel economy values, and curb weights that have all been updated to reflect the application of technologies in response to CAFE requirements. For each vehicle model in this fleet, the system then estimates the following: lifetime travel, fuel consumption, and carbon dioxide and criteria pollutant emissions. After aggregating model-specific results, the system estimates the magnitude of various economic externalities related to vehicular travel (*e.g.*, noise) and energy consumption (*e.g.*, the economic costs of short-term increases in petroleum prices).

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[7] As needed, we typically develop a "synthesized" forecast by assembling available data for a recent model year and inflating sales volumes consistent with overall market forecasts.

Different categorization schemes are relevant to different types of effects. For example, while energy and carbon dioxide calculations group vehicles by type of fuel, criteria pollutant calculations group vehicles by U.S. Environmental Protection Agency (EPA) emissions classes. Therefore, unlike many other modeling systems, this system uses model-by-model categorization and accounting when calculating most effects, and aggregates results only as required for efficient reporting.

B. CAFE Compliance Simulation

B.1. Compliance Simulation Algorithm

Each time the modeling system is used, it evaluates one or more CAFE scenarios. Each of these scenarios is defined in the "compliance model parameters" input file described in Appendix C. Each scenario describes an overall CAFE program in terms of the program's coverage, the definition of nonpassenger automobiles, the stringency of the standards applicable to passenger automobiles, and the structure and stringency of the standards applicable to nonpassenger automobiles. The first scenario is identified as the baseline scenario, providing results to which results for any other scenarios are compared. Although many scenarios can be examined with each run of the model, for simplicity in this overview, we will only describe one scenario occurring in one model year.

The compliance simulation applies technology to each manufacturer's product line based on the CAFE program described by the current scenario and the assumed willingness of each manufacturer to pay civil penalties rather than complying with the program. The first step in this process involves definition of the fleet's *initial state*—that is, the volumes, prices, and attributes of all vehicles as projected without knowledge of CAFE standards—during the study period, which can cover one or more consecutive model years (MYs) during MY2002-MY2015. The second step involves evaluating the applicability of each available technology to each vehicle model, engine, and transmission in the fleet. The third and final step involves the repeated application of technologies to specific vehicle models, engines, and transmissions in each manufacturer's fleet. For a given manufacturer, this step terminates when CAFE standards have been achieved or all available technologies have been exhausted. Alternatively, if the user specifies that some or all manufacturers should be considered willing to pay CAFE fines (*i.e.*, civil penalties for noncompliance), this step terminates when it would be less expensive to pay such fines than to continue applying technology.

Initial State of the Fleet

The fleet's initial state is developed using information contained in the vehicle models, engine, and transmission worksheets described in Appendix C. The set of worksheets uses identification codes to link vehicle models to appropriate engines, transmissions, and preceding vehicle models. Figure 1 provides a simplified example illustrating the basic structure and interrelationship of these three worksheets, focusing primarily on structurally important inputs. These identification codes make it possible to account for the use of specific engines or transmissions across multiple vehicle models. They also help the compliance simulation algorithm to appropriately "carry over" technologies between model years.

Vehicle Models Worksheet

Veh ID	Model	FE	Sales		Price		Engine Code	Transmission Code	Predecessor
			MY08	MY09	MY08	MY09			
223	M1a	20.95	22,301	21,726	27,750	28,125	1	2	
224	M2a	21.78	57,118		22,500		1	3	
225	M3a	18.33	32,089		31,250		2	4	
227	M4a	22.02		45,793		24,250	3	3	
228	M3b	18.51		37,283		31,500	4	4	225

Engines Worksheet

Eng ID	Name	Fuel	Cyl	Displacement	Valve per Cylinder
1	E1a	G	6	3.5	2
2	E2a	G	8	4.0	2
3	E1b	G	6	3.5	4
4	E2b	G	8	4.0	4

Transmissions Worksheet

Trans ID	Name	Type	Gears	Control
1	M5	C	5	M
2	A4a	T	4	A
3	A5b	T	5	A
4	A4c	T	4	A

Figure 1. Basic Structure of Input File Defining the Fleet's Initial State

Technology Application

Having defined the fleet's initial state, the system applies technologies to each manufacturer's fleet based on the CAFE program for the current model year. The system currently represents the set of technologies considered by the NAS in its 2002 study of the CAFE program. The Final Economic Analysis of the recent rulemaking establishing MY2005-MY2007 nonpassenger automobile standards explains why we have used this set of technologies and the accompanying NAS assumptions regarding cost impacts and fuel consumption benefits.[8] In addition to this set of technologies, the system also provides a means of representing "Dieselization" (*i.e.*, replacement of gasoline with Diesel engines), the use of hybrid powertrains, and materials substitution to change vehicle weight. Table 2 lists the technologies represented by the system, and the grouping we have applied to enable the system to follow a constrained path within any given group without being unnecessarily prevented from considering technologies in other groups. This "parallel path" approach is discussed below.

Table 2. Technologies

Engine Technologies	Transmission Technologies	
Low Friction Lubricants	5-Speed Automatic Transmission	
Engine Friction Reduction	6-Speed Automatic Transmission	
Multi-Valve, Overhead Camshaft	Automatic Transmission w/ Aggressive Shift Logic	
Variable Valve Timing	Continuously Variable Transmission (CVT)	
Cylinder Deactivation	Automatic Shift Manual Transmission (AST/AMT)	
Variable Valve Lift & Timing	Advanced CVT	
Engine Supercharging & Downsizing		
Camless Valve Actuation		
Intake Valve Throttling		
Variable Compression Ratio		
Dieselization[9]		
Materials Substitution	Dynamic Load Reduction	Other
Material Substitution 1	Improved Rolling Resistance	Electric Power Steering
Material Substitution 2	Aero Drag Reduction[10]	Engine Accessory Improvement
Material Substitution 3		42 Volt Electrical Systems
Material Substitution "Plus"[11]		Integrated Starter/Generator

As discussed in Appendix C, input assumptions for each of these technologies are specified in the technologies input file, and are specific to each of the following vehicle types: small SUVs, midsize SUVs, large SUVs, minivans, small pickups, large pickups, subcompact cars, compact cars, midsize cars, and large cars. Table 3 lists the input assumptions specified in this file.

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[8] [add reference]

[9] Replacing a gasoline engine with a Diesel engine.

[10] Aerodynamic improvements have been assigned to a separate technology group.

[11] Increasing vehicle weight through materials substitution.

Table 3. Technology Input Assumptions

Input	Meaning
FC-Low	minimum reduction (%) of fuel consumption
FC-High	maximum reduction (%) of fuel consumption
Cost-Low	minimum added cost[12] (retail price equivalent in 2003 dollars)
Cost-High	maximum added cost[12] (retail price equivalent in 2003 dollars)
Year Avail.	first model year available
Path1	inclusion on technology application path #1
Path2	inclusion on technology application path #2
Path3	inclusion on technology application path #3
Phase-In	maximum share of fleet (%) to which technology may be added in any single model year
k_{Weight}	percent change reduction of curb weight (materials substitution only)
Abbr.	abbreviation for technology
seq	sequence for ordering technologies within each technology group
TechType	technology group (see Table 2)

As discussed below, the system uses estimates of each technology's impact on cost and fuel consumption when selecting which technologies to apply to which vehicles in order to achieve compliance with CAFE standards. Within each technology group (as specified using the "TechType" field mentioned above), the system considers technologies based on their order of appearance (which corresponds to the "seq." field), taking into account overall availability (as specified using the "Year Avail." field) and any constraints on the rate of uptake (as specified using the "Phase-In" field). As discussed below, the applicability of a given technology to one of the types of vehicles mentioned above is determined, at least provisionally, by the inclusion or exclusion of the technology on the selected "NAS Path" (*i.e.*, Path1, Path2, or Path3). The user defines these paths in an input file discussed in greater detail in Appendix C (see Table C-5). The user also specifies which path is to be applied. As discussed below, the precise sequence with which technologies are applied to different vehicle models is determined using an optimization algorithm subject to several user-specified constraints in addition to those related to the choice and definition of path.

Unless the current model year is the first or only model year in the study period, the compliance simulation algorithm first applies any technologies that should be "carried over" from the previous model year. This carryover is implemented based on any "predecessor" relationships specified in the vehicle models input file, and increases the cost and fuel economy of affected vehicles in the current model year.[13] Carrying over technologies between model years based on such relationships avoids some unlikely predictions, such as that a given technology would be added to a given vehicle model in one model year and then removed in the following model year.

[12] Because materials substitution is applied as a percentage of curb weight, the corresponding cost estimates are in dollars per pound of incremental change in curb weight.

[13] Because it occurs without reference to CAFE standards applicable to the current model year, this technology carryover can cause overcompliance with one or more CAFE standards, depending on overall changes in the manufacturer's fleet.

The algorithm next determines the applicability of each technology to each vehicle model, engine, and transmission. If the technology is available in the current model year and included on the NAS technology application path selected by the user (*e.g.*, if the user has selected "Path 2" and Path2 is set to "TRUE" for the appropriate vehicle type and the technology in question), the system identifies the technology as potentially applicable. However, technology "overrides" can be specified for specific vehicle models, engines, and transmissions in the corresponding input files.[14] If any such overrides have been specified, the algorithm reevaluates applicability as shown in Figure 2.

[14] These overrides, described in Appendix C (see Table C-2), provide a means of accounting for engineering and other issues not otherwise represented by input data or the overall system.

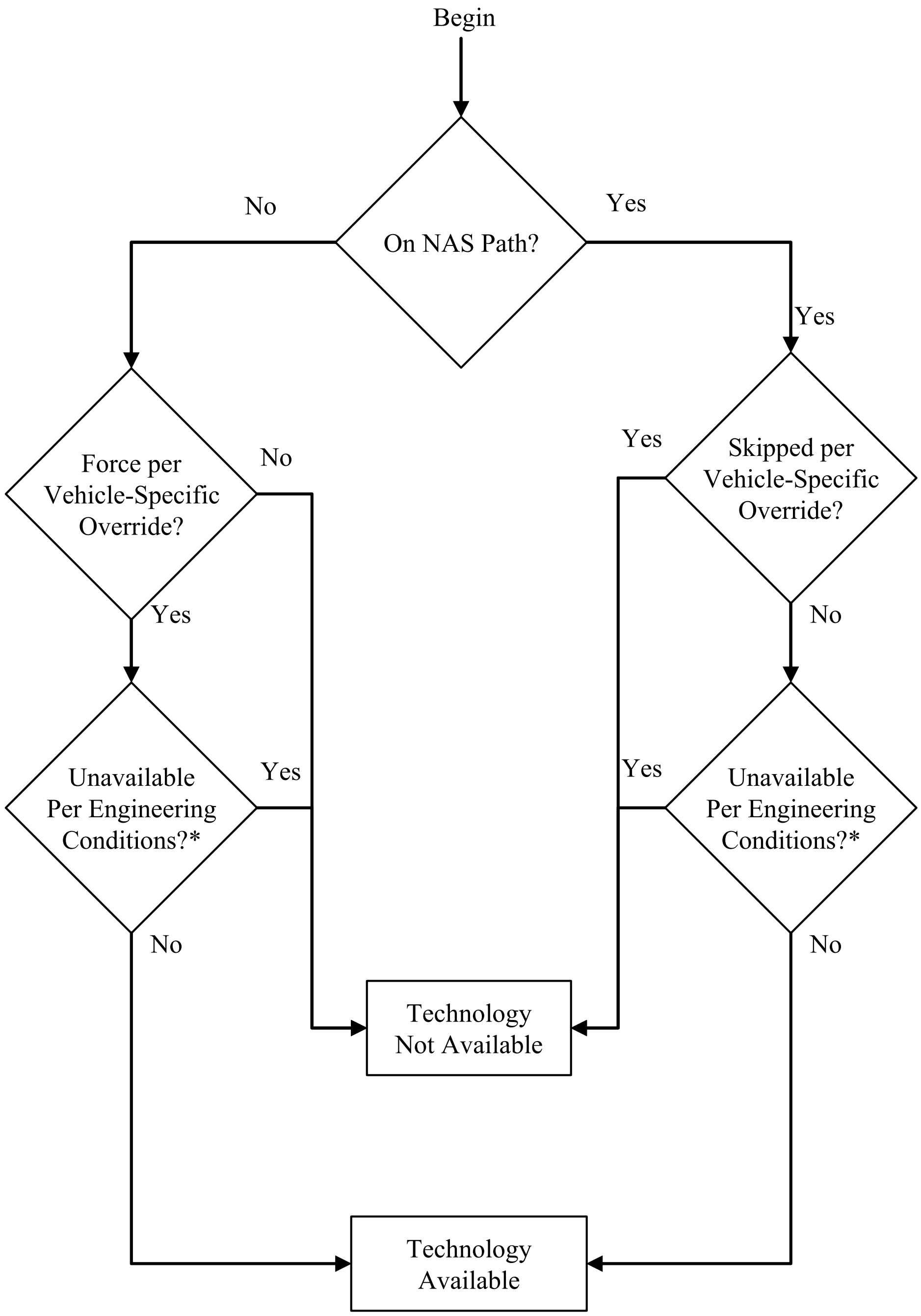


Figure 2. Technology Applicability Determination

If a given technology is still considered applicable after considering any overrides, the algorithm again reevaluates applicability based the following engineering conditions:

Table 4. Engineering Conditions for Technology Applicability

Technology	Constraint
Low-Friction Lubricants	Do not apply if engine oil is better than 5W30
Variable Valve Timing (VVT)	Do not apply to OHV engines or engines with displacement greater than 3.5 *l*
Variable Valve Lift and Timing (VVLT)	Do not apply to engines with displacement greater than 3.0 *l* or that do not already have VVT
Cylinder Deactivation	Do not apply to engines with VVT, VVLT, multivalve OHC, and/or fewer than 6 cylinders.
Continuously Variable Transmission	Apply only to FWD unibody vehicles.
Front Axle Disconnect	Apply only to 4WD vehicles with cylinder count greater than six.
Electric Power Steering	For vehicles with curb weights over 4,000 pounds, do not apply unless 42-Volt systems are already present.
Integrated Starter-Generator	Do not apply to SUVs with seating less than 7 or pickups with seating less than 4
Weight Reduction	Do not apply to vehicles with curb weights below 5,000 pounds.

Having determined the applicability of each technology to each vehicle model, engine, and/or transmission, the compliance simulation algorithm begins the process of applying technologies based on the CAFE standards applicable during the current model year. This involves repeatedly evaluating the degree of noncompliance, identifying the “best next” technology available on each of the parallel technology paths mentioned above, and applying the best of these. Figure 3 gives an overview of the process. If, considering all regulatory classes, the manufacturer owes no CAFE fines, the algorithm applies no technologies beyond any carried over from the previous model year. If the manufacturer does owe CAFE fines, the algorithm first finds the best next applicable technology in each of the technology groups (*e.g.*, engine technologies), and applies the same criterion to select the best among these. If this manufacturer is assumed to be unwilling to pay CAFE fines (or, equivalently, if the user has set the system to exclude the possibility of paying fines as long as some technology can still be applied), the algorithm applies the technology to the affected vehicles. If the manufacturer is assumed to be <u>willing</u> to pay CAFE fines and applying this technology would have a lower “effective cost” (discussed below) than simply paying fines, the algorithm also applies the technology. In either case, the algorithm then reevaluates the manufacturer’s degree of noncompliance. If, however, the manufacturer is assumed to be willing to pay CAFE fines and doing so would be less expensive than applying the best next technology, the algorithm stops applying technology to this manufacturer’s products. After this process is repeated for each manufacturer, the compliance simulation algorithm concludes.

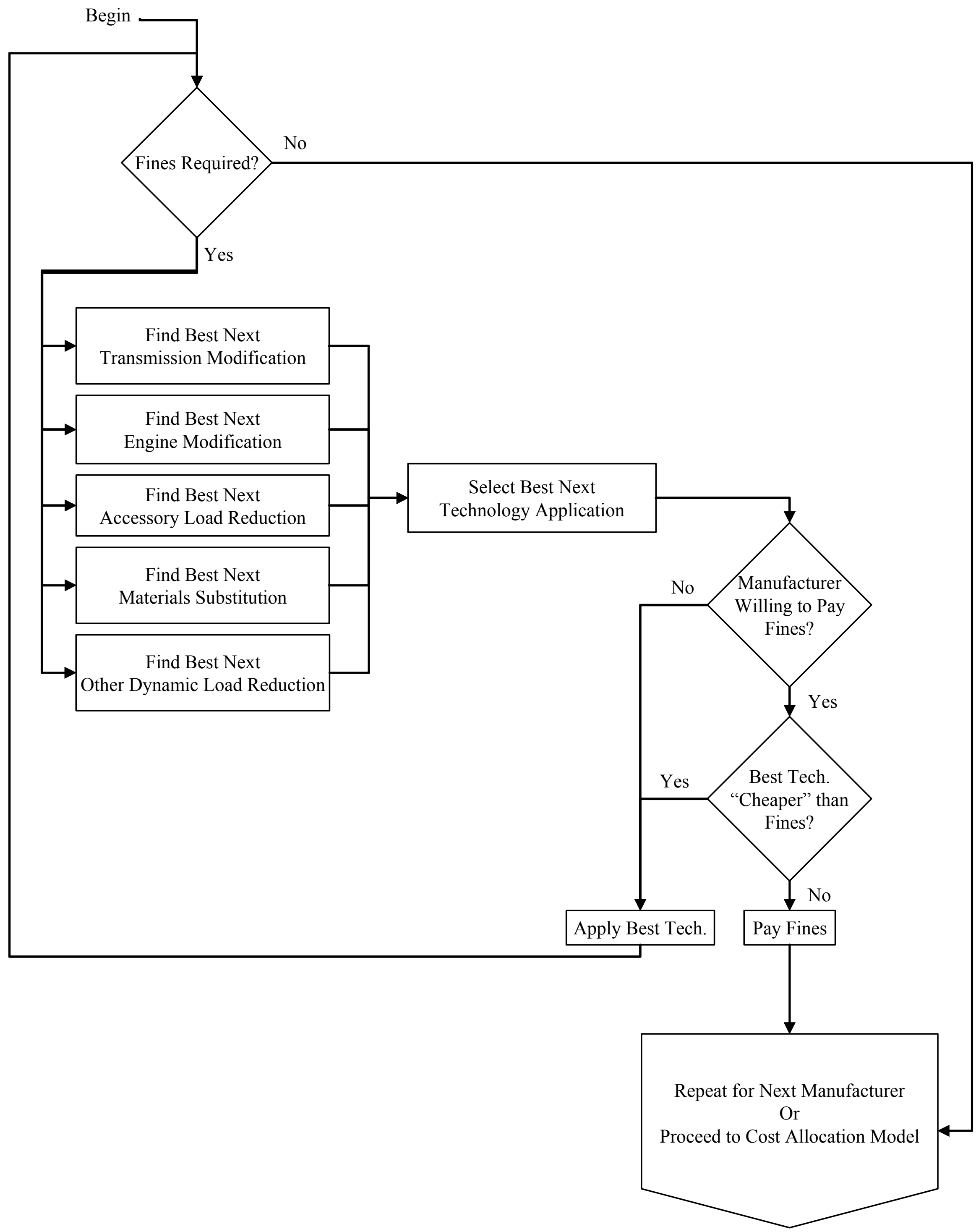


Figure 3. Compliance Simulation Algorithm

Whether or not the manufacturer is assumed to be willing to pay CAFE fines, the algorithm uses CAFE fines not only to determine whether compliance has been achieved, but also determine the relative attractiveness of different potential applications of technologies. Whenever the algorithm is evaluating the potential application of a technology, it considers the effective cost of applying that technology to the group of vehicles in question, and chooses the option that yields the lowest effective cost.[15] The effective cost is used for evaluating the relative attractiveness of different technology applications, not for actual cost accounting. The effective cost is defined as the change in total technology costs incurred by the manufacturer plus the change in CAFE fines incurred by the manufacturer minus the value of any reduction of fuel consumed by vehicles sold by the manufacturer:

$$COST_{eff} = \frac{\Delta TECHCOST + \Delta FINE - VALUE_{FUEL}}{N_j} \tag{1.1}$$

where $\Delta TECHCOST$ is simply the product of the unit cost of the technology and the total sales (Nj) of the affected cohort of vehicles (j). The value of the reduction in fuel consumption achieved by applying the technology in question to all vehicles i in cohort j is calculated as follows:[16]

$$VALUE_{FUEL} = \sum_{i \in j} \left[N_i \sum_{v=0}^{v=PB} \frac{SURV_v MI_v FUELPRICE_{MY+v}}{(1-gap)(1+r)^{v+0.5}} \left(\frac{1}{FE_i} - \frac{1}{FE_i'} \right) \right] \tag{1.2}$$

where MI_v is the number of miles driven in a year at a given vintage v, $SURV_v$ is the probability that a vehicle of that vintage will remain in service, FE_i and FE_i' are the vehicle's fuel economy prior to and after the pending application of technology, gap is the relative difference between on-road and laboratory fuel economy, N_i is the sales volume for model i in the current model year MY, $FUELPRICE_{MY+v}$ is the price of fuel in year $MY+v$, and PB is a "payback period", or number of years in the future the consumer is assumed to take into account when considering fuel savings. As discussed in Appendix C, MI_v, $SURV_v$,$FUELPRICE_{MY+v}$, and PB are all specified in the compliance model parameters file.

In (1.1), $\Delta FINE$ is the change in total CAFE fines (*i.e.*, accounting for all regulatory classes in the current CAFE scenario and model year). Typically, $\Delta FINE$ is negative because applying a technology would increase CAFE.[17] $\Delta FINE$ is calculated by evaluating the following before and after the pending technology application, and taking the difference between the results:

$$FINE = -k_F \left[\sum_{c \notin T} \mathrm{MIN}\left(CREDIT_c, 0\right) + \mathrm{MIN}\left(\sum_{c \in T} CREDIT_c, 0 \right) \right] \tag{1.3}$$

---

[15] Such groups can span regulatory classes. For example, if the algorithm is evaluating a potential upgrade to a given engine, that engine might be used by a station wagon in the domestic passenger automobile fleet, a large car in the imported passenger automobile fleet, and a minivan in the nonpassenger automobile fleet. If the manufacturer's domestic and imported passenger automobile fleets both comply with the corresponding standard, the algorithm accounts for the fact that upgrading this engine will incur costs and realize fuel savings for all three of these vehicle models, but will only yield reductions of CAFE fines for the nonpassenger fleet.

[16] This is not necessarily the "actual" value of the fuel savings, but rather the increase in vehicle price the manufacturer is assumed to expect to be able impose without losing sales.

[17] Exceptions can occur if materials substitution is applied under a weight-based system.

Here, T is the set of vehicles among which credit trading is allowed (*i.e.*, the "trading pool") and k_F is in dollars per mpg (*e.g.*, \$55/mpg) and specified in the compliance model parameters file. Currently, the trading pool is either an empty set (if credit trading is not allowed in the current scenario) or includes all classes of nonpassenger automobiles (if credit trading is allowed). Credit trading between manufacturers is not accommodated. The system assumes that as regulatory classes, both domestic and imported passenger automobiles are excluded from any such trading.[18] Therefore, for any system in which nonpassenger automobiles are covered as a single regulatory class, no credit trading is allowed. Also, the system currently implements credit trading only within a single model year, and does not attempt to account for credit "carry forward" (*i.e.*, banking) or "carry back" between model years.

Within each regulatory class C, the <u>net</u> amount of CAFE credit created (noncompliance causes credit creation to be negative, which implies the <u>use</u> of CAFE credits) is calculated by subtracting the CAFE level achieved by the class from the standard applicable to the class, and multiplying the result by the number of vehicles in the class. Taking into account the possibility of attribute-based CAFE standards (for nonpassenger automobiles), this is expressed as follows:

$$CREDIT_c = N_c\left[\mathrm{STD}_c\left(\mathbf{N}_c,\mathbf{A}_c\right)-\mathrm{CAFE}_c\left(\mathbf{N}_c,\mathbf{FE}_c\right)\right] \qquad (1.4)$$

where $\mathbf{A}_C$ is a vector containing the value of the relevant attribute for each vehicle model in regulatory class C, $CAFE_C$ is the CAFE level for regulatory class C (*e.g.*, if the standard depends on curb weight, $\mathbf{A}_C$ contains each vehicle model's curb weight), $\mathbf{FE}_C$ is a vector containing the fuel economy level of each vehicle model in regulatory class C, N_C is the total sales volume for regulatory class C, $\mathbf{N}_C$ is a vector containing the sales volume for each vehicle model in regulatory class C, and $\mathrm{STD}_C(\mathbf{N}_C, \mathbf{A}_C)$ is a function defining the standard applicable to regulatory class C. For all systems that use flat CAFE standards, $\mathrm{STD}_C(\mathbf{N}_C, \mathbf{A}_C)$ reduces to STD_C (*e.g.*, 27.5 mpg).

Figure 4 gives an overview of the logic the algorithm follows in order to identify the best next technology application for each technology group.

[18] Under current CAFE provisions, CAFE credits may be transferred across model years (subject to limitations) but may not be transferred between the domestic passenger automobile, imported passenger automobile, and nonpassenger automobile fleets. For systems that divide nonpassenger automobiles into multiple regulatory classes, we accommodate the possibility that trading between these new classes might or might not be allowed.

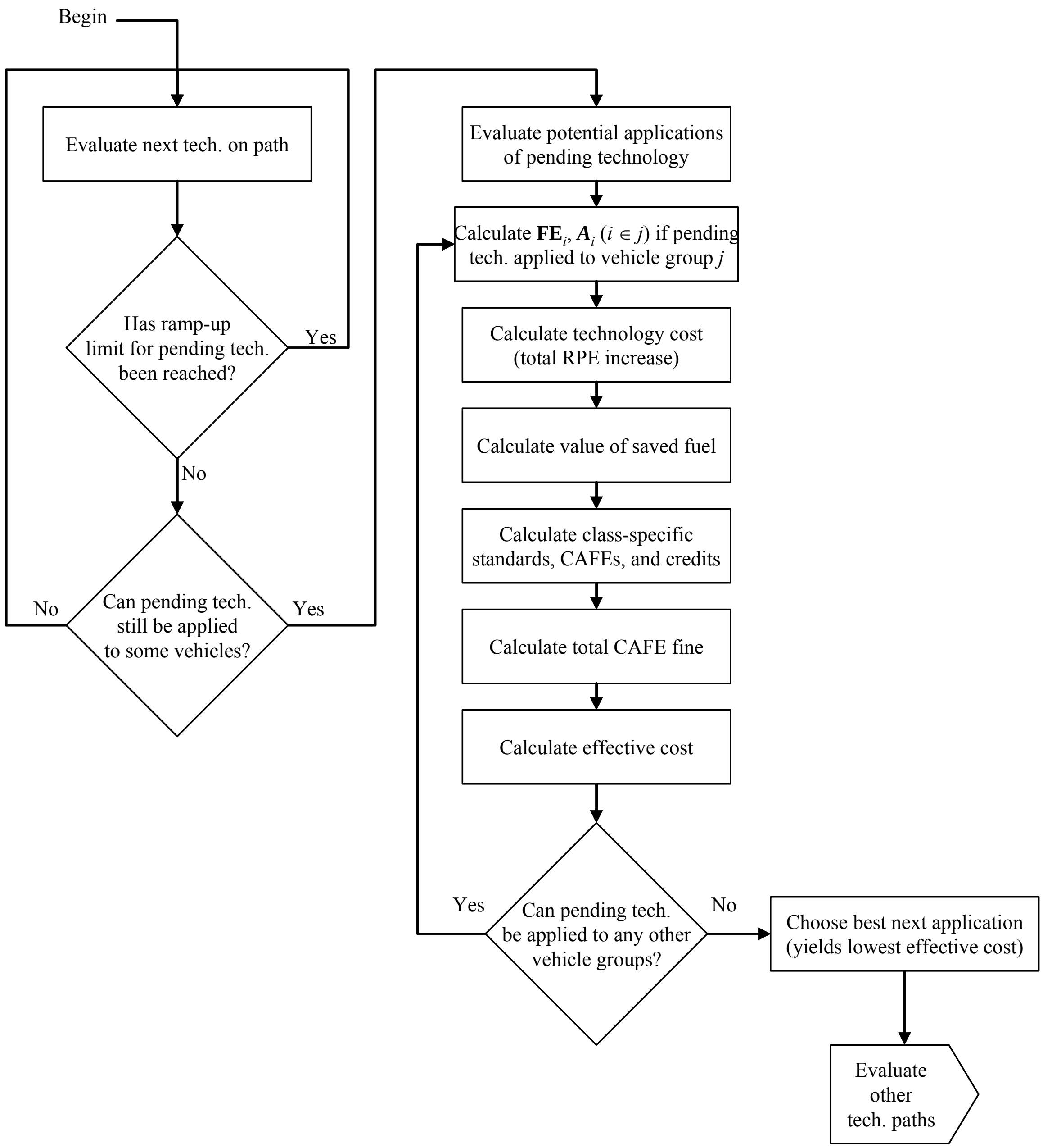


Figure 4. Determination of "Best Next" Technology Application

Within a given technology group, the algorithm considers technologies in the order in which they appear. If the phase-in limit for a given technology has been reached, the algorithm proceeds to the next technology. If not, the algorithm determines whether or not the technology remains applicable to any sets of vehicles, evaluates the effect cost of applying the technology to each such set, and identifies the application that would yield the lowest effective cost. As shown in Figure 3, the algorithm repeats this process for each technology group, and then selects the technology application yielding the lowest effective cost.

C. Calculation of Effects

This section describes how the effects of tightening or reforming CAFE standards on energy use, emissions of air pollutants and greenhouse gases are estimated. These effects are caused by improvements in the fuel economy of some vehicle models as manufacturers respond to changes in the CAFE standards, together with changes in the composition and use of the light-duty vehicle fleet resulting from new vehicle buyers' responses to changes in the prices and fuel economy levels of new vehicle models. This section also describes how these various impacts are translated into estimates of economic benefits or costs, and identifies whether these economic impacts are or borne privately by vehicle owners or by society as a whole.

The effects on energy use, emissions from tightening or reforming CAFE standards are estimated separately for each individual vehicle model and vintage (model year) over its expected life span in the U.S. vehicle fleet.[28] A vehicle's life span extends from the initial year when it is produced and sold until the time when all vehicles from that model year have been scrapped or retired

[28] [deleted]

from service, assumed to be 30 years after it is sold.[29] Each of these effects is measured by the difference in the value of a variable – such as total gallons of fuel consumed by a vehicle model and vintage during a future calendar year – with the baseline CAFE standard (usually the standard currently in effect for that class of vehicle) remaining in effect, and if those vehicles were instead required to comply with a stricter CAFE standard.

Although these effects are calculated for individual vehicle models and vintages, they are typically reported at the aggregate level for all vehicle models in each CAFE class (domestic automobiles, import automobiles, and light trucks) produced during each model year affected by the stricter standard. These aggregated values are reported for each future calendar year during which a model year remains in the vehicle fleet. Cumulative impacts for each CAFE class and model year over its expected life span are also reported, both in undiscounted terms and as their present value discounted to the calendar year when each model year is offered for sale.[31]

Light-Duty Vehicle Sales and Fleet

The forecast number of new vehicles of a specific model *k* sold during a given model year *MY* is:

$$n_{k,MY} = N_{MY} P_{k,MY} \tag{1.13}$$

Where N_{MY} indicates the forecast of total new light-duty vehicle sales during that model year, and the forecast market share of each vehicle model produced during that year, $P_{k,MY}$, is obtained from (1.6), (1.7), and (1.8), as discussed previously in Section III.B.[32]

The number of vehicles of a specific model and vintage that remains in service during each subsequent calendar year is calculated by applying estimates of the proportion of vehicles initially sold that remain in service at each age. Thus the number of vehicles of model k produced during model year m that remain in use during a future year *t*, or $n_{k,MY,t}$, is:

$$n_{k,MY,t} = n_{k,MY} s_{k,t} \tag{1.14}$$

where $s_{k,t}$ denotes the proportion of vehicles of model *k* expected to remain in use during year *t*. During year *t*, those vehicles will have reached age *a*, where $a = t - MY + 1$.[33] The model utilizes different schedules of expected survival rates by vehicle age for six separate classes of

[29] We adopt the simplification that vehicle model years and calendar years are identical.

[31] [deleted]

[32] The subscripts denoting buyers (*n*) and the market segment (*s*) that includes vehicle model *k* are dropped to simplify this and the following expressions.

[33] We define a vehicle's age to be 1 during the year when it is produced and sold; that is, when $t=MY$. Thus for example, a model year 2005 vehicle is defined to be 10 years old during calendar year 2014. Because we do not attempt to forecast *changes* in the proportion of vehicles produced during future model years that are expected to survive to each age, a vehicle's age is depends only on the difference between its model year (*MY*) and the calendar year (*t*) for which these calculations are performed, and not on their specific values.

light-duty vehicles, as reported in Appendix C. As the absence of a *MY* subscript from the parameter *s* indicates, we assume that these survival rates will not vary for future model years.

C.1. Vehicle Use and Total Mileage

The total number of miles driven by vehicles of a specific model and vintage (or model year) during each year they remain in the fleet is calculated by multiplying age-specific estimates of annual miles driven per vehicle by the number of vehicles of that model year remaining in service at the age corresponding to that future year. As with survival rates, the average number of miles driven by a specific vehicle model at each age during its expected lifetime differs depending on its vehicle class. Thus the total miles driven by vehicles of model *k* produced during model year *MY* that are expected to remain on the road during year *t*, denoted $M_{k,MY,t}$ is calculated as:

$$M_{k,MY,t} = n_{k,MY,t} m_{k,MY,t} \qquad (1.15)$$

where $m_{k,MY,t}$ is the average number of miles that a surviving vehicle of model *k* is driven during year *t*, when those vehicles will have reached age $a = t - MY + 1$. The model uses separate estimates of average annual utilization at different ages for different classes of light-duty vehicles, as discussed in Appendix C. As with survival rates, we assume that annual usage of each vehicle type at each age during its expected lifetime will remain unchanged for future model years.

Separate estimates of average annual utilization at different ages are used for automobiles and several different classes of light-duty trucks, as discussed in Appendix C.

Accounting for the "Rebound Effect"

Improving a vehicle's fuel economy reduces the cost of driving by reducing the amount of fuel required to drive each mile. In response to the lower per-mile cost of driving a more fuel-efficient vehicle, some buyers will increase the amount of driving they do, although the precise nature and magnitude of this response is uncertain. Thus imposing stricter fuel economy standards results in a slight increase in the annual number of miles driven by vehicle models whose fuel economy is improved as a result of manufacturers' efforts to comply with those standards.[34] This increase in the annual use of vehicle models whose fuel economy is improved, referred to as the "rebound effect" in vehicle use, results in a corresponding increase in the total number of miles driven by vehicles produced during each model year affected by the stricter standards during each year they remain in the fleet.

The proportional increase in the average annual number of miles driven during year *t* by a vehicle model *k* when its fuel economy is improved from the level specified by its manufacturer's product plan for its model year, denoted $mpg_{k,MY,plan}$, to a higher level,

[34] The rebound effect also produces additional benefits to vehicle owners in the form of consumer surplus from the increase in driving, which is discussed in Section C.6.

$mpg_{k,MY,CAFE}$, is calculated using a standard form for the elasticity of travel demand with respect to the fuel cost of driving:

$$\frac{\Delta m_{k,MY,t,CAFE}}{m_{k,MY,t}} = \varepsilon_{cpm} \left[\frac{\dfrac{f_t}{mpg_{k,CAFE}} - \dfrac{f_t}{mpg_{k,plan}}}{\dfrac{f_t}{mpg_{k,plan}}} \right] \qquad (1.16)$$

where ε_{cpm} is the elasticity of vehicle use with respect to the cost of fuel per mile driven, a measure of the rebound effect, and f_t is the price of fuel per gallon during future year t . Because the fuel cost per mile driven by any vehicle is equal to the price of fuel per gallon divided by its fuel economy in miles per gallon, the bracketed term in (1.16) represents the proportional reduction in fuel cost per mile driven resulting from the improvement in fuel economy.[35]

Thus the absolute increase in average miles driven by vehicles of model k during year t that results from the standard is:

$$\Delta m_{k,MY,t,CAFE} = \varepsilon_{cpm} \left(\frac{mpg_{k,MY,plan}}{mpg_{k,MY,CAFE}} - 1 \right) m_{k,MY,t} \qquad (1.17)$$

Finally, the increase in the total number of miles driven by vehicles of model k and model year MY each future year t they remain in the fleet, denoted $\Delta M_{k,MY,t,CAFE}$ is calculated from:

$$\Delta M_{k,MY,t,CAFE} = n_{k,MY,t} \Delta m_{k,MY,t,CAFE} \qquad (1.18)$$

where $n_{k,MY,t}$ is given by (1.14).

Total miles driven each year increases due to the rebound effect only for those vehicle models whose fuel economy is improved as part of their manufacturers' efforts to comply with a CAFE standard that applies during the model year they are produced. In contrast, there is no increase in annual usage of vehicle models whose fuel economy remains unchanged from the level specified in manufacturers' product plans for that model year.

The existence of the rebound effect also means that any scenario requiring a vehicle manufacturer to increase the fuel economy of some models from those indicated in its product plan for that model year results in an increase in their use over each year of their expected lifetime. Thus where a manufacturer's product plan specifies fuel economy levels that will result in non-compliance with the CAFE standard in effect during the previous model year, any improvement in the fuel economy of its models necessary to ensure compliance with that baseline standard will produce a slight increase in their lifetime use through the rebound effect.

[35] For (1.16) to be strictly correct, *mpg* must represent actual "on the road" fuel economy. The difference between laboratory test and actual on-road fuel economy is discussed in detail in Section C.2. below.

The effect on total annual mileage driven resulting from substituting a new CAFE standard (denoted $CAFE_1$) for a previous standard ($CAFE_0$) is the difference in the added driving from the rebound effects associated with the two standards:

$$\Delta M_{k,a,t,CAFE1} - \Delta M_{k,a,t,CAFE0} = n_{k,a,t}\left(\Delta m_{k,a,t,CAFE1} - \Delta m_{k,a,t,CAFE0}\right) \quad (1.19)$$

C.2. Fuel Use and Savings

Fuel consumption by vehicles of each specific model and vintage during a future year depends on the total mileage that the surviving vehicles are driven during that year, and the average fuel efficiency they obtain in actual driving. Computing this value is complicated by the presence of the rebound effect, which as discussed previously causes slightly higher annual usage throughout the lifetime of any vehicle model whose fuel economy is improved above the level specified in its manufacturer's product plan.

Another complication is posed by the difference between the fuel economy levels of new vehicles as measured for purposes of assessing CAFE compliance and the (lower) levels they actually achieve in real-world driving. Finally, it is also necessary to calculate fuel use separately for gasoline and diesel vehicles, since these fuels result in different levels of greenhouse gas and air pollutant emissions.

The number of gallons of fuel consumed by vehicles of model k and model year MY during year t, denoted $g_{k,MY,t}$, is calculated from:

$$g_{k,MY,t} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY}\left(1 - gap\right)} \quad (1.20)$$

where *gap* indicates the difference between that model's fuel economy as measured for CAFE purposes and its actual on-road fuel economy. We assume 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.[36]

When the value of $mpg_{k,MY}$ in this expression corresponds exactly to the value specified in the product plan submitted by vehicle k's manufacturer for model year MY, there is no rebound effect (*i.e.*, $\Delta M_{k,MY,t} = 0$), and

$$g_{k,MY,t,plan} = \frac{M_{k,MY,t}}{mpg_{k,MY,plan}\left(1 - gap\right)} \quad (1.21)$$

[36] These assumptions explain the absence of an age subscript on *mpg*, and of all subscripts on the parameter *gap*.

For any vehicle model whose fuel efficiency its manufacturer elects to increase as part of its strategy to comply with a CAFE standard (including an extension to future model years of the prevailing standard), the appropriate form of (1.20) is:

$$g_{k,MY,t,CAFE} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} \qquad (1.22)$$

or, equivalently:

$$g_{k,MY,t,CAFE} = \frac{M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} + \frac{\Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} \qquad (1.23)$$

where the second term on the right hand side represents the additional fuel consumption attributable to the standard's inducement of additional driving through the rebound effect. The effect on total fuel use during year *t* resulting from substituting a different standard (denoted $CAFE_1$) for one previously in effect ($CAFE_0$) is obtained by summing expression (1.22) or (1.23) over all vehicle models produced during the model years to which the alternative standard would apply:

$$G_{t,CAFE1} = \sum_{MY} \sum_{k} \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) \qquad (1.24)$$

Thus the change in fuel use that results from imposing a different CAFE standard is always measured *relative to* expected fuel use with some baseline or comparison standard in effect. A frequent assumption is that this baseline standard would be an extension of the same standard that applies to vehicles produced during the preceding model year.

Cumulative fuel savings from imposing a stricter standard on vehicles produced during a single model year *MY* over the years they are assumed to remain in service are:

$$G_{MY,CAFE1} = \sum_{t} \sum_{k} \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) \qquad (1.25)$$

An often more appropriate measure of these fuel savings is the present value of lifetime fuel savings for model year *MY* vehicles, discounted to the year they are produced (*i.e.*, their model year), or:

$$PV\left(G_{MY,CAFE1}\right) = \sum_{t} \sum_{k} \left(\frac{g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}}{(1+d)^{t-MY}} \right) \qquad (1.26)$$

where *d* is the annual discount rate. Appendix C specifies the discount rate used in our model.

Greenhouse Gas Emissions

Environmental impacts from petroleum use stem primarily from combustion of petroleum products such as gasoline, and to a lesser extent from petroleum refining and the distribution and storage of refined products. These impacts include emissions of greenhouse gases, which are widely believed to increase the potential for global climate change, and of regulated or "criteria" air pollutants, which at sufficient concentrations can adversely affect human health and damage property.

Tighter CAFE standards for light-duty trucks will reduce gasoline consumption and the amount of petroleum refined, and both of these effects will in turn reduce emissions of greenhouse gases. While reduced gasoline refining will also lower emissions of criteria pollutants, the increase in vehicle use that results from improving their fuel economy via the rebound effect will raise emission of these pollutants. Thus on balance, CAFE standards can reduce or increase emissions of criteria pollutants, depending on vehicles' emission rates per mile driven and on the size of the rebound effect.

Fuel savings from stricter light truck CAFE standards will result in lower emissions of carbon dioxide, the main greenhouse gas emitted as a result of refining, distribution, and use of transportation fuels.[37] Lower fuel consumption reduces carbon dioxide emissions directly, because the primary source of these emissions in transportation is fuel use in internal combustion engines. We calculate reductions in carbon dioxide emissions from vehicle operation by multiplying the volume of fuel consumed by the amount of carbon converted to carbon dioxide during the combustion process per unit volume of fuel.[38]

Direct or "tailpipe" carbon emissions (in the form of carbon dioxide) generated during year t from fuel consumption by vehicles of model k produced during model year MY are calculated from:

$$C_{k,MY,t}^{tp} = g_{k,MY,t} c_f \tag{1.27}$$

where c_f indicates the carbon content (by weight) per gallon of fuel. As with fuel use, this calculation is performed separately for carbon emissions resulting from gasoline and diesel fuel combustion. The carbon content of gasoline is assumed to be a weighted average of those for different types of gasoline in use (see Appendix C for fuel-specific carbon content and the assumed mix of gasoline types).

As with fuel consumption, the effect of a proposed CAFE standard on carbon emissions from vehicle operation is measured by the difference in emissions with the proposed standard in effect and those with a baseline or other alternative standard. Denoting these $CAFE_1$ and $CAFE_0$ as previously, the change in carbon emissions from fuel consumed by vehicles of model k and model year MY during year t is

$$C_{k,MY,t,CAFE1}^{tp} = \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right) c_f \tag{1.28}$$

[37] Carbon dioxide emissions account for more than 97% of total greenhouse gas emissions from the refining and use of transportation fuels; see U.S. Environmental Protection Agency, *Draft Inventory of GHG Emissions and Sinks (1990-1999)*, Tables ES-1 and ES-4, http://www.epa.gov/globalwarming/publications/emissions/us2001/energy.pdf.

[38] Although the system does not explicitly account for incomplete conversion of carbon to carbon dioxide, input values specifying carbon content can be adjusted accordingly (*i.e.*, reduced to 99-99.5% of actual carbon content).

Again, this calculation is performed separately for carbon emissions from gasoline and diesel fuel use. Its results can be summed over the vehicle models and vintages affected by a proposed standard to estimate its impact on carbon emissions during future years, or over vehicle types and years to estimate the proposed standard's effect on lifetime carbon emissions of vehicles produced during the model years it would affect.

At the same time, changing the stringency of CAFE standards will affect carbon emissions generated by fuel combustion and other energy use that occurs during crude petroleum extraction, transportation and storage, and refining to produce each type of fuel, as well as during the storage and distribution of refined fuel (often referred to as "upstream" emissions). Carbon emissions from each of these activities are calculated using estimates of emission rates per unit of fuel energy refined and distributed to retail fueling stations.

These estimates are converted to a per-gallon basis using the energy content of different types of gasoline and of diesel fuel, and used to calculate total carbon emissions per gallon of fuel used. For vehicles of model *k* and model year *MY*, total carbon emissions during year *t* from fuel production, distribution, and use are calculated as:

$$C^{tot}_{k,MY,t} = g_{k,MY,t}\left(c_f + r \cdot c_r + c_d\right) \quad (1.29)$$

where as above c_f is the carbon content of each fuel type, c_r includes carbon emissions per gallon during crude petroleum extraction, transportation, and refining to produce that type of fuel, c_d represents carbon emissions per gallon during storage and distribution of refined fuel, and r is the fraction of that fuel type refined domestically (rather than imported directly). The values of these parameters are specified in Appendix C.

The effect of replacing an initial or baseline standard $CAFE_0$ with an alternative standard $CAFE_1$ on total carbon emissions from fuel production and use is:

$$C^{tot}_{k,MY,t,CAFE1} = \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right)\left(c_f + r \cdot c_r + c_d\right) \quad (1.30)$$

Again, this quantity can be summed over vehicle models and ages to estimate the effect of a proposed standard on total carbon emissions during any future year, or over vehicle types and years to estimate the standard's effect on lifetime total carbon emissions of vehicles affected by it.

C.3. Air Pollutant Emissions

Stricter CAFE standards can result in higher or lower emissions of regulated or "criteria" air pollutants, by-products of fuel combustion that are emitted in extremely small amounts by the internal combustion engines used to power light-duty vehicles as well as in gasoline refining and distribution. Criteria pollutants emitted in significant quantities by light-duty motor vehicles include carbon monoxide, various hydrocarbon compounds, nitrogen oxides, sulfur dioxide, and fine particulate matter.

On one hand, the increased use of some vehicle models that occurs through the effect of higher fuel economy on the fuel cost per mile driven (the rebound effect) causes increased emissions of criteria pollutants, since federal standards regulate permissible emissions of these pollutants on a per-mile basis. Additional emissions of these pollutants from vehicle operation are estimated by multiplying the increase in total miles driven using vehicle models and vintages whose fuel economy is improved by per-mile emission rates for each of these pollutants.

Emissions of pollutant *i* resulting from the operation of vehicle model *k* and model year *MY* during year *t* are calculated as:

$$E^{tp}_{i,k,MY,t} = \left(M_{k,MY,t} - \Delta M_{k,MY,t}\right) e_{i,k,MY,t} \quad (1.31)$$

where ($M_{k,MY,t}$ + $\Delta M_{k,MY,t}$) is given by (1.20), and $e_{i,k,MY,t}$ is emissions per mile of pollutant *i* by vehicles of model *k* and model year *m* during year *t*, when they will have reached age $a = t - MY$. Emissions of each pollutant per mile driven are estimated as functions of vehicle age for different classes of light-duty vehicles, using the U.S. EPA's MOBILE motor vehicel emission factor model (see Appendix C). As with other measures, emissions can be summed for calendar or model years.

Changes in the volume of fuel consumption from varying CAFE standards will also affect emissions of criteria pollutants that occur during refining, distribution, and retailing of gasoline and diesel fuel.[39] As with greenhouse gas emissions, these "upstream" emissions are estimated by applying emission factors for each criteria pollutant per unit of fuel refined to the total volume of each type of fuel consumed with any specified CAFE standard in effect.

Upstream emissions of pollutant *i* generated in producing and distributing each type of fuel consumed by vehicles of model *k* and vintage *MY* during year *t* are:

$$E^{up}_{i,k,MY,t} = g_{k,MY,t}\left(r \cdot e_{i,r} - e_{i,d}\right) \quad (1.32)$$

where $g_{k,MY,t}$ is calculated from (1.20), *r* is the fraction of each fuel type refined domestically, $e_{i,r}$ is emissions of pollutant *i* that occur during crude petroleum extraction, transportation, and refining, and $e_{i,d}$ is emissions of that pollutant from the storage and distribution of refined fuel. Both $e_{i,r}$ and $e_{i,d}$ are expressed per gallon of fuel produced.

Total emissions of criteria pollutant *i* from the production, distribution, and use of fuel are the sum of emissions during vehicle operation and from the production and distribution of fuel:

$$E^{tot}_{i,k,MY,t} = E^{tp}_{i,k,MY,t} + E^{up}_{i,k,MY,t} \quad (1.33)$$

[39] As with carbon dioxide emissions, reductions in criteria pollutant emissions from fuel refining and distribution are calculated using emission rates obtained from Argonne National Laboratories' GREET model; see Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model*, Version 1.6, February 2000, http://www.transportation.anl.gov/ttrdc/greet/index.html.

In turn, the effect on criteria pollutant emissions of substituting standard $CAFE_1$ for an alternative standard $CAFE_0$ is

$$E^{tot}_{i,k,MY,t,CAFE1} = \left(\Delta M_{k,MY,t,CAFE1} - \Delta M_{k,MY,t,CAFE0}\right) e_{i,k,MY,t} + \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right)\left(r \cdot e_{i,r} + e_{i,d}\right) \quad (1.34)$$

As usual, this quantity can be summed over model or calendar years to report annual or lifetime effects of proposed CAFE standards on emissions of criteria pollutants.

Emissions of some criteria pollutants are likely to increase as a result of stricter CAFE standards, as increased emissions from added driving due to the rebound effect outweigh the reduction in emissions from gasoline refining and distribution. For other pollutants, however, emission rates during fuel production are large relative to those from vehicle operation, so the reverse is likely to be true. As a result, the pattern of net changes in criteria pollutant emissions varies significantly, both over future years and among individual pollutants during any year.

C.6. Private and Social Costs and Benefits

Improving the fuel efficiency of new vehicles produces a wide range of benefits and costs, some of which affect buyers of those vehicles directly, while others are borne more broadly by society as a whole. Depending upon how manufacturers attempt to recoup the costs they incur for improving the fuel efficiency of selected models, buyers are likely to face higher prices for some – and perhaps even most – new vehicle models. Purchasers of models whose fuel economy is improved benefit from the resulting savings in the value of fuel their vehicles consume, from any increase in the range they can travel before needing to refuel, and from the added driving they do as a result of the rebound effect. Depending on the technology manufacturers use to improve fuel economy and its consequences for vehicle power and weight, these benefits may be partly offset by a slight decline in the performance of some new models.

At the same time, the reduction in fuel production and use resulting from improved fuel economy produces certain additional benefits and costs to society as a whole. Potential social benefits from reduced fuel use include any value society attaches to fuel savings over and above its private value to new vehicle buyers, lower emissions of air pollutants and greenhouse gases generated by from fuel production, distribution, and consumption, and reduced economic costs associated with U.S. imports of crude petroleum and refined fuel. By causing some additional driving through the rebound effect, improving fuel economy can also increase a variety of social costs, including the economic value of health effects and property damages caused by increased air pollution, the value of time delays to motorists from added traffic congestion, added costs of injuries and property damage resulting from more frequent traffic accidents, and economic costs from higher levels of traffic noise.

[41] *Ibid.*, p. 5.

The following sections discuss how each of these benefits and costs can result from improving the fuel economy of new vehicles, the factors affecting their likely magnitudes, and how their values are commonly measured or estimated. Appendix C provides the specific unit economic values and other parameters used to estimate the aggregate value of these various benefits and costs, explains how these values were derived, and reports the specific sources from which they were obtained.

Benefits and Costs to New Vehicle Buyers

Increases in New Vehicle Prices

Depending upon how manufacturers attempt to recover the costs they incur in complying with CAFE regulations, purchase prices for some new models are likely to increase. Because we assume that manufacturers fully recover all costs they incur for installing fuel economy technologies to comply with CAFE in the form of higher prices for some models, the total increase in vehicle sales prices has already been accounted for in estimating technology costs to manufacturers. Nevertheless, the total value of these price increases represent a cost of CAFE regulation from the viewpoint of new buyers of models whose prices rise.

In addition to increases in the prices paid by buyers who elect to purchase these models even at their higher prices, higher prices result in losses in welfare or consumer surplus to buyers who decide to purchase different models instead. These losses are extremely complex to estimate if prices change for a large number of models, and in any case are likely to be small even in total. Thus we do not attempt to estimate their value.

The Value of Fuel Savings

We estimate the economic value of fuel savings to buyers of new vehicle models whose fuel economy is improved as part of their manufacturers' efforts to comply with stricter CAFE standards by applying the Energy Information Administration's *Annual Energy Outlook* forecast of future fuel prices to each year's estimated fuel savings for those models. The annual fuel savings for a model during each year of its lifetime in the vehicle fleet is multiplied by the number of those initially sold that are expected to remain in use during that year to determine the total annual value of fuel savings to buyers of that model.

The forecast retail price of fuel per gallon—including federal and average state fuel and other taxes—during that year is used to estimate the value of these fuel savings as viewed from the perspective of their buyers. Based on evidence from previous studies of consumer purchases of automobiles and durable appliances, we assume that new vehicle buyers value these savings over the approximate number of years they expect to own a new vehicle, and that buyers discount these expected savings to the year in which they purchase new vehicles.

Benefits from Additional Driving

The rebound effect results in additional benefits to new vehicle buyers in the form of consumer surplus from the increased driving it produces. These benefits arise from the value to drivers and passengers of the social and economic opportunities made available to them by additional traveling. As evidenced by the fact that they elect to make more frequent or longer trips when improved fuel economy reduces the cost of driving, the benefits from this additional travel exceed the costs drivers and their passengers incur in making more frequent or longer trips. The amount by which these benefits from additional travel exceed its cost—which has been reduced by lower fuel consumption—represents the increase in consumer surplus associated with additional rebound effect driving.

Our analysis estimates the value of these benefits using the conventional approximation, which is 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. This value is calculated for each year that a model whose fuel economy is improved remains in the fleet, multiplied by the number of vehicles of that model expected to remain in use during each year of its lifetime, and discounted to its present value as of the year it was purchased. This benefit is likely to be small by comparison to most other economic impacts of raising CAFE standards.

The Value of Extended Refueling Range

Manufacturers' efforts to improve the fuel economy of selected new vehicle models will also increase their driving range between refueling. By reducing the frequency with which drivers typically refuel their vehicles, and by extending the upper limit of the range they can travel before requiring refueling, improving fuel economy thus provides some additional benefits to their owners.[42] No direct estimates of the value of extended vehicle range are readily available, so our analysis calculates the reduction in the annual number of required refueling cycles that results from improved fuel economy.

The change in required refueling frequency for vehicle models with improved fuel economy reflects the increased driving associated with the rebound effect, as well as the increased driving range stemming from higher fuel economy.

[42] If manufacturers instead respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting savings in costs will presumably be reflected in lower sales prices.

Changes in Performance and Utility

In its recent report on CAFE, the NAS assumed that, when applying efficiency-related technologies in response to CAFE standards, manufacturers would hold vehicle performance and utility constant. We make the same assumption.

Social Benefits and Costs from Increased Fuel Economy

The "Social Value" of Fuel Savings

The economic value to society of the annual fuel savings resulting from stricter CAFE standards is also assessed by applying estimated future fuel prices to each year's estimated fuel savings. Unlike the value of fuel savings to vehicle buyers themselves, however, the *pre-tax* price per gallon is used in assessing the value of fuel savings *to the economy as a whole*. This is because reductions in revenues generated by state and federal taxes on fuel will be exactly offset by reduced spending on the government programs – mainly construction and maintenance of streets and highways -- they are used to finance, and thus do not reflect a net savings in resources to the economy.

When estimating the nationwide aggregate economic benefits and costs from CAFE regulation, we include this "social" value of fuel savings rather than their private value to vehicle buyers. In computing the social value of fuel savings, we include their annual value over the entire expected lifetimes of vehicle models whose fuel economy is improved, reflecting the presumably longer-term horizon of society as a whole compared to that of vehicle buyers, who may be concerned with fuel savings only over the time they expect to own newly-purchased vehicles.

Economic Benefits from Reduced Petroleum Imports

Importing petroleum into the United States is widely believed to impose significant costs on households and businesses that are not reflected in the market price for imported oil, and thus are not borne by consumers of refined petroleum products. These costs include three components: (1) higher costs for oil imports resulting from the combined effect of U.S. import demand and OPEC market power on the world oil price; (2) the risk of reductions in U.S. economic output and disruption of the domestic economy caused by sudden reductions in the supply of imported oil; and (3) costs for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the Strategic Petroleum Reserve (SPR) to cushion against price increases. By reducing domestic demand for gasoline, tighter CAFE standards may reduce petroleum imports, thus lowering some or all of these external or social costs to the U.S. economy from importing oil. If so, this represents an additional category of economic benefits from tighter fuel economy standards.

Demand costs for imported oil (often termed "monopsony" costs) arise because the world oil price appears to be partly determined through the exercise of market power by the OPEC cartel, and because the U.S. is a sufficiently large purchaser of foreign oil supplies that its purchases can affect the world price. The combination of OPEC market power and U.S. "monopsony" power means that increasing domestic petroleum demand that is met through higher oil imports can cause the world price of oil to rise, and conversely that declining U.S. imports can reduce the world price of oil. Thus one consequence of increasing U.S. oil imports is an increase in the price paid for all oil consumed by the U.S., which is borne not only by purchasers of the additional imports, but also by all purchasers of imported and domestically-produced petroleum.[43]

The key determinants of the magnitude of this demand cost are the degree of monopoly power over foreign oil supplies exercised by the OPEC cartel, and the role of U.S. imports in determining world oil demand. If OPEC exercises some monopoly power over international oil supplies and U.S. import demand can affect the world price, changes in the level of domestic petroleum imports can influence world prices, thus creating the demand component of the economic cost of importing additional oil into the U.S. Under these same conditions, reductions in U.S. demand for imported petroleum would *reduce* the world oil price, thus creating additional benefits for all domestic oil consumers beyond the savings they experience simply from purchasing less oil.

The degree of current OPEC monopoly power is subject to considerable debate, but appears to have declined somewhat since the 1970s. Nevertheless, the consensus appears to be that OPEC remains able to exercise some degree of control over the response of world oil supplies to variation in world oil prices, so that the world oil market does not behave competitively. The extent of U.S. monopsony power is determined by a complex set of factors including the relative importance of U.S. imports in the world oil market, and the sensitivity of petroleum supply and demand to its world price among other participants in the international oil market. Most recent evidence suggests that variation in U.S. demand for imported petroleum continues to exert some influence on world oil prices, although this influence appears to be limited.

The second component of the external economic costs of importing oil arises partly because the increase in oil prices triggered by a disruption in the supply of imported oil reduces the level of output that the U.S. economy can produce using its available resources. The resulting reduction in potential economic output depends on the extent and duration of any disruption in the supply of imported oil to the U.S., since these determine the resulting increase in prices for petroleum products, as well as on whether and how rapidly these prices return to their pre-disruption levels. Even if the price for imported oil returns to its original level, however, the nation's economic output will be at least temporarily reduced compared to the level that would have been possible without the disruption in oil supplies and consequent increase in energy prices.

Because supply disruptions and resulting price increases occur suddenly rather than gradually, they also impose additional costs on businesses and households for adjusting their use of

[43] For example, if the U.S. initially imports 10 million barrels per day at a world oil price of $20 per barrel, its total daily import bill is $200 million. If increasing imports to 11 million barrels per day causes the world oil price to rise to $21 per barrel, the daily U.S. import bill rises to $231 million. The resulting increase of $31 million per day is attributable to increasing daily imports by only 1 million barrels, which means that the incremental cost of importing each additional barrel is $31, or $10 more than the newly-increased world price of $21 per barrel. This additional $10 per barrel represents the cost imposed on all users of imported oil by those demanding the increased level of imports, a cost in excess of the price they pay to obtain those additional imports. Note, however, that this additional cost arises only because the increase in U.S. oil imports affects the world oil price.

petroleum products and other sources of energy more rapidly than if the same price increase had occurred gradually over time. These adjustments temporarily reduce the level of economic output that can be achieved even below the level that would ultimately be reached once the economy's adaptation of output levels and energy use to higher petroleum prices was complete. The additional costs imposed on businesses and households for making these rapid adjustments reflect their inability to change their product prices, output levels, and use of energy and other resources quickly and smoothly in response to rapid changes in prices for petroleum products.

Since future disruptions in foreign oil supplies are an uncertain prospect, each of these two components of the disruption cost must be weighted or adjusted for the probability that the supply of imported oil to the U.S. will actually be disrupted. Thus the "expected value" of these costs – the product of the probability that an oil import disruption will occur and the sum of costs from reduced economic output and the economy's abrupt adjustment to sharply higher petroleum prices -- is the usual measure of their magnitude. Further, only the *change* in their expected value that results from lowering the normal (pre-disruption) level of oil imports through a policy such as tightening CAFE standards is relevant when assessing its effect on the "true" cost of importing oil into the U.S.

While the vulnerability of the U.S. economy to oil price shocks is widely thought to depend on *total* petroleum consumption rather than on the level of oil imports, variation in imports is still likely to have some effect on the potential price increase resulting from any disruption of import supply. In addition, changing the quantity of petroleum imported into the U.S may also affect the probability that such a disruption will occur. If the resulting price increase or the probability that U.S. oil imports will be disrupted is affected by their pre-disruption level, the expected value of the costs stemming from supply disruptions will also vary in response to the level of oil imports.

An increasing number of market mechanisms – including oil futures markets, energy conservation measures, and fuel switching possibilities -- are available within the U.S. economy for businesses and households to anticipate and "insure" themselves against the effects of petroleum price increases. While their availability has undoubtedly reduced the potential costs that could be imposed by disruptions in the supply of imported oil, the full expected value of these potential costs still may not be reflected in the market price of imported oil. Thus changes in oil import levels probably continue to affect the expected cost to the U.S. economy from potential oil supply disruptions, although the value of this component of oil import costs is likely to be significantly smaller than those estimated by studies conducted in the wake of the oil supply disruptions that occurred during the 1970s.

The third component of the external economic costs of importing oil into the U.S. is usually identified as the costs to the U.S. taxpayers for maintaining a military presence to secure the supply of oil imports from potentially unstable regions of the world and protect the nation against their interruption. Some analysts also include the costs to federal taxpayers for maintaining the U.S. Strategic Petroleum Reserve, which is intended to cushion the U.S. economy against the consequences of disruption in the supply of imported oil, as additional costs of protecting the U.S. economy from such oil supply disruptions. Thus many analyses include part or all of the annual cost for U.S. military operations in the Persian Gulf (and occasionally other regions of the world), together with the full costs of stocking and maintaining the SPR, as additional economic costs associated with importing oil into the U.S.

However, there is little evidence that the magnitude of either of these costs is associated with *changes* in the actual level of oil imports into the U.S. that would result from policies such as tightening CAFE standards. In addition, military activities even in world regions that represent vital sources of oil imports undoubtedly serve a range of security and foreign policy objectives that is considerably broader than simply protecting oil supplies. As a consequence, the scope and duration of any specific U.S. military activities that were undertaken for the purpose of protecting imported oil supplies seem unlikely to be tailored to the actual volume of petroleum imports from the regions where they take place. Thus annual expenses to support U.S. military activities do not seem likely to vary closely in response to changes in the level of oil imports prompted by conservation efforts or other policies. More specifically, reductions in gasoline use resulting from stricter CAFE standards seem unlikely to result in savings in the military budget that could be included as additional benefits.

Similarly, while the optimal size of the SPR from the standpoint of its potential influence on domestic oil prices during a supply disruption may be related to the level of U.S. oil consumption and imports, its actual size has not appeared to vary in response to recent changes in the volume of oil imports. Thus while the budgetary costs for maintaining the Reserve are similar to other external costs in that they are not likely to be reflected in the market price for imported oil, these costs have not varied in response to changes in oil import levels (although in theory they might ideally do so). As a result, this analysis does not include any cost savings from maintaining a smaller SPR among the external benefits of reducing gasoline consumption and petroleum imports by means of a tighter CAFE standard for light-duty trucks.

In this analysis, the reduction in petroleum imports resulting from higher light truck CAFE standards is estimated by assuming that the resulting savings in gasoline use during each future year is translated directly into a corresponding reduction in the annual volume of U.S. oil imports during that same year. The value to the U.S. economy of reducing petroleum imports -- in the form of lower crude oil prices and reduced risks of oil supply disruptions – is estimated by applying the sum of the previously-reported estimates of these benefits to the estimated annual reduction in oil imports.

Valuing Changes in Environmental Impacts

Environmental impacts from petroleum use occur primarily as a result of petroleum refining and the distribution and combustion of petroleum products such as gasoline. These impacts include emissions of greenhouse gases, which are widely believed to increase the potential for global climate change, and of regulated or “criteria” air pollutants, which can adversely affect human health and damage property in sufficient concentrations. Emissions of greenhouse gases and criteria pollutants occur during petroleum refining, as well as during the subsequent distribution and consumption of petroleum products such as gasoline. Stricter CAFE standards will reduce gasoline consumption and the amount of petroleum refined, and both of these effects will in turn reduce emissions of greenhouse gases. While reduced gasoline refining and distribution will also lower emissions of criteria pollutants, the increased driving that results from improving the fuel economy of new vehicles will raise emissions of these pollutants. On balance, CAFE standards can thus reduce or increase emissions of criteria pollutants.

We value the net change in emissions of each criteria pollutant to which gasoline refining and motor vehicle operation contribute significantly – carbon monoxide, volatile organic compounds, nitrogen oxides, sulfur dioxide, and fine particulates – using estimates of the value per ton of emissions of each pollutant that is eliminated.

Social Costs of Added Driving

In addition to the slight increase in emissions of criteria pollutants, the added driving associated with the fuel economy rebound effect may contribute to increased traffic congestion, motor vehicle accidents, and highway noise. Additional vehicle use can contribute to traffic congestion and delays partly by increasing recurring congestion on heavily-traveled facilities during peak travel periods, depending on how the additional travel is distributed over the day and on where it occurs. Added vehicle use can also increase the frequency of incidents such as collisions and disabled vehicles that cause prolonged delays, although the extent to which it actually does do will again depend partly on when and where the added travel occurs. In either case, any added delays caused by additional vehicle use imposes higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses, and these should be considered as an external cost associated with the increase in driving from the rebound effect.

At the same time, the added light truck use due to the rebound effect may also increase the economic costs of injuries and property damage from traffic accidents. Drivers presumably take account of the potential costs they (and the other occupants of their vehicles) face from the possibility of being involved in an accident when they decide to make additional trips. However, they may not consider fully the potential costs they impose on occupants of other vehicles and on pedestrians, so any increase in these “external” accident costs that results from added rebound-effect driving must be estimated separately. Like increased delay costs, any increase in these external accident costs caused by added driving is likely to depend on the traffic conditions under which it takes place, since accidents are more frequent in heavier traffic, but their severity may be reduced by the slower speeds at which heavier traffic typically moves. Thus estimates of the increase in external accident costs from the rebound effect also need to account for when and where the added driving occurs.

Finally, added light truck use from the rebound effect may also increase traffic noise. Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, to pedestrians and other bystanders, and to residents or occupants of surrounding property. Because none of these effects are likely to be taken into account by the drivers whose vehicles contribute to traffic noise, it represents an additional externality associated with motor vehicle use. Although there is considerable uncertainty in estimating its value, the added inconvenience and irritation caused by increased traffic noise imposes economic costs on those it affects. Thus to the extent that added driving from the fuel economy rebound effect causes an increase in traffic noise, the resulting increase in these costs must be included together with other increased external costs from the rebound effect.

Our analysis uses estimates of the increases in external costs – that is, the marginal costs – from added congestion, property damages and injuries in traffic accidents, and noise levels caused by additional usage of automobiles and light-duty trucks.

Appendix A. Installation

The CAFE Compliance and Effects Modeling System runs on IBM-compatible computers using the Microsoft® Windows operating system. A processor speed of at least 1 GHz is highly recommended, as is physical RAM of at least 512 Mb.[44] The software has been developed on computers using Windows XP, but may operate properly on machines using older versions (*e.g*, Windows 2000) of Windows compatible with the Microsoft® .NET Framework.

Because the software makes extensive use of Microsoft® Excel files for input and output, Excel must be present. To provide a means of protecting confidential business information contained in input and output files, the software makes use of encryption algorithms available in Excel 2003. These algorithms are not available in older versions of Excel. Unencrypted files may be used with such versions.

The software uses the Microsoft® .NET Framework. If the Framework is not already present, it must be installed. Instructions are available on the Internet at http://msdn.microsoft.com/netframework/downloads/framework1_1/.[45]

Once the .NET Framework has been successfully installed, contact NHTSA or Volpe Center staff to obtain the files needed to install the CAFE Compliance and Effects Modeling System. Those files will be accompanied by current instructions for installing the system.

Based on the characteristics of machines used in the development of this software, Table A-provides a summary of system recommendations.

Table A-1. System Recommendations

1GHz or faster processor
512Mb or more RAM
Microsoft® Windows XP
Microsoft® Excel 2003
Microsoft® .NET Framework 1.1

[44] If the software exhausts the available physical RAM, it will begin using the system's virtual memory (*i.e.*, the hard disk) and will slow dramatically.

[45] Microsoft released a service pack (SP1) for this version (1.1) of the .NET Framework on August 30, 2004. We have not tested our system with either this service pack or with a Beta version 2.0 of the Framework.

Appendix B. Operation

Step 1: Install the software (see Appendix A) and put all the input files in a folder you can find. The files are:

- *demo_ parameters.xls*: inputs used to calculate the energy, emissions of changes in vehicle characteristics and sales volumes, as well as some assumptions used when simulating compliance

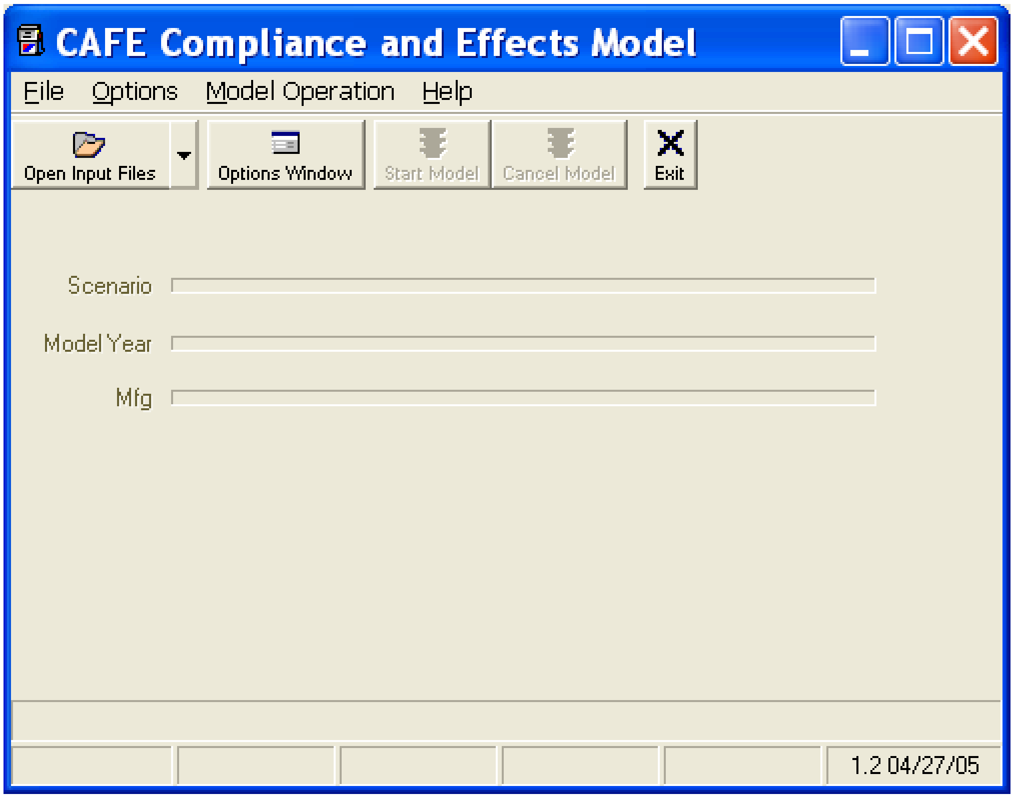
- *demo_market_data.xls*: vehicle model, engine, and transmission characteristics and vehicle model sales volumes

- *demo_scenarios.xls*: inputs used to define different CAFE scenarios

- *demo_technologies.xls*: technology cost, efficiency, and availability assumptions

To protect confidential business information and otherwise protected information, the file defining the initial state of the fleet—*demo_market_data.xls*—contains fictitious entries for many fields. Therefore, when used with this file, the system will produce fictitious results. Though useful for diagnostic purposes, such results should be treated as otherwise meaningless, and should not be cited or released.

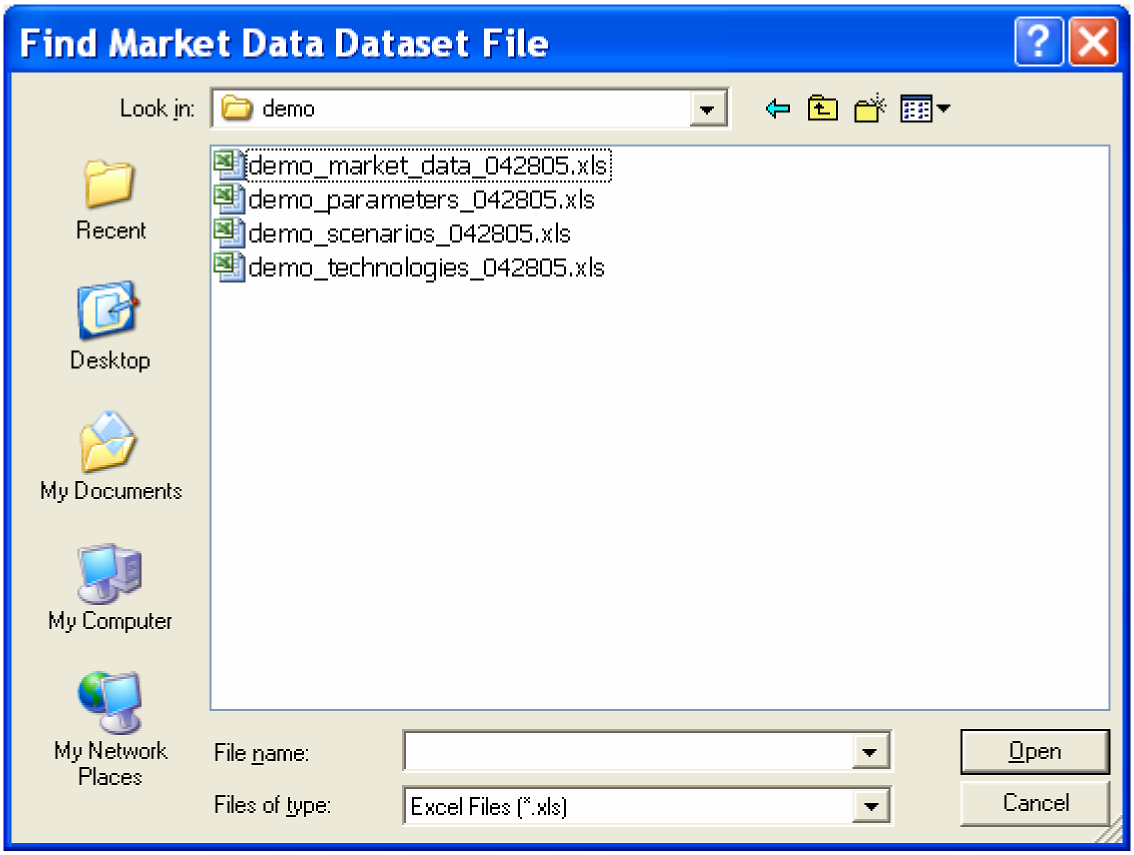
Step 2: After closing other applications (in particular, Excel), run the program to open the main control window.[46]



[46] Because the software slows dramatically if the physical RAM is fully utilized, we recommend closing other applications while you're running the software. Also, because of the way the software accesses Excel to open input files and create output files, it's important to make sure that Excel is closed before running the software.

Step 3: Use the "Open...Files" control buttons to specify the input file locations.

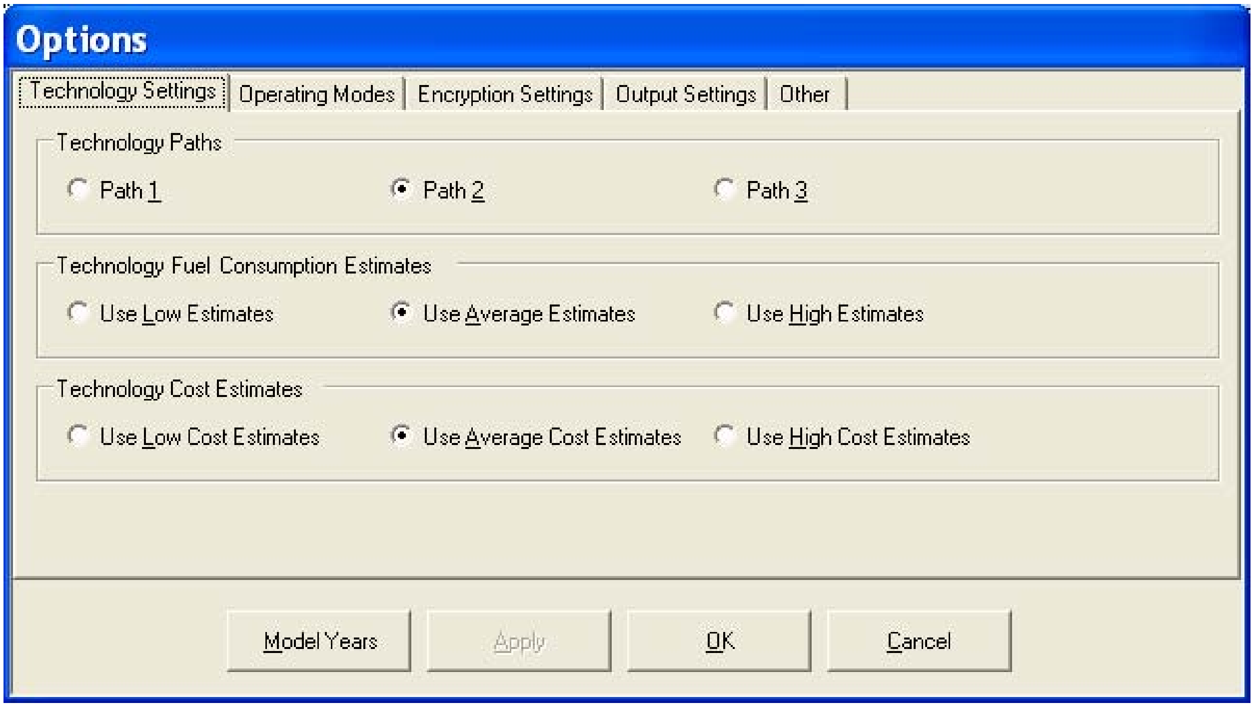
- Select "Open Market Data File" from the File menu and locate the market data file when prompted.



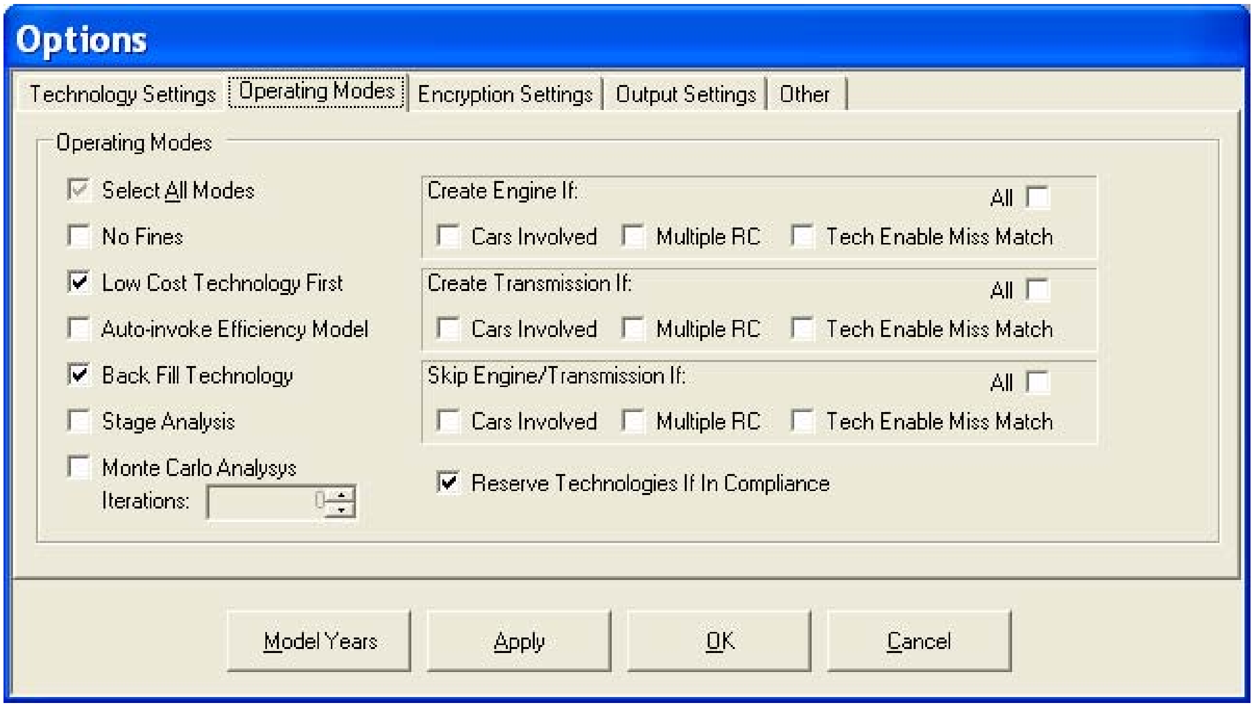
- Click the "Open Other Files" and locate technologies, parameters, and benefits model parameters files when prompted. (**NOTE: To be able to select the benefits model parameters file, first go to the "Other" tab located on the "Options" window and check "Run the Effects Model at the end of each scenario". See Step 4.**)

Step 4. Use the "Options" button to open model operation controls.

- Click the "Technology Settings" tab and change settings as desired.



- Click the “Operating Modes” tab and change settings as desired.[47,48,49]



[47] add text to more fully explain operating modes

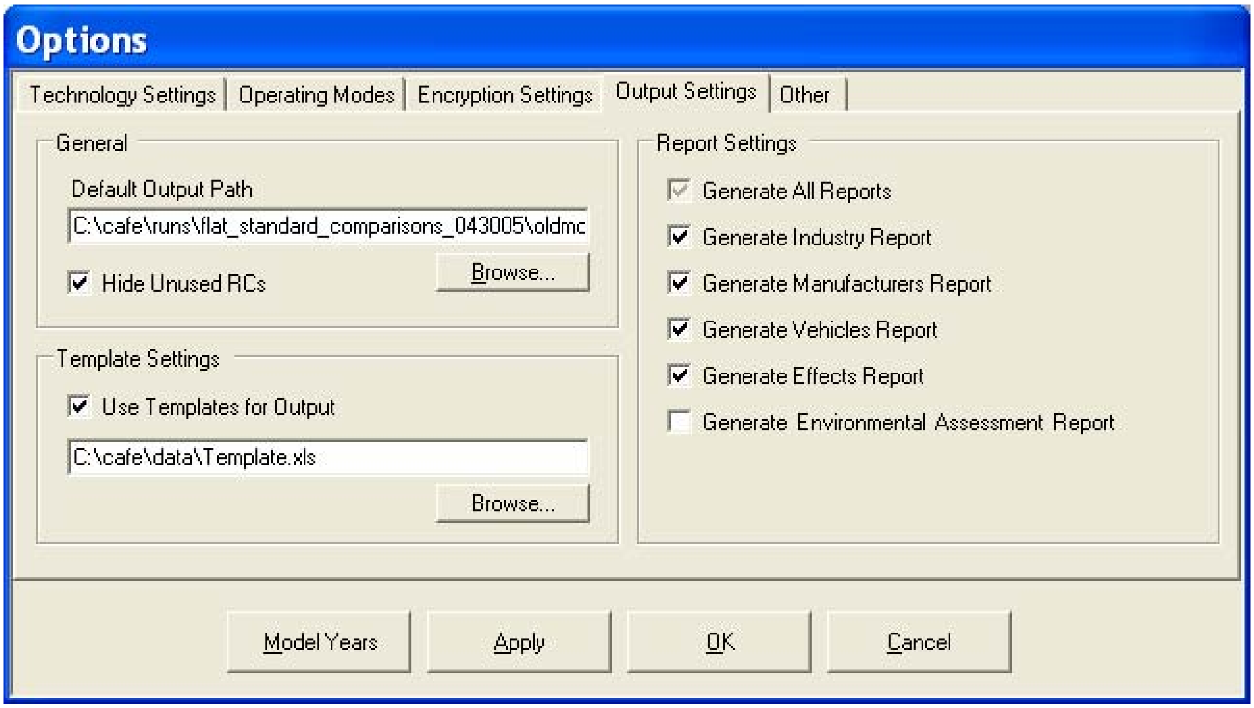
[48] “Low Cost First” directs program to meet phase-in caps for first technologies in each technology group before proceeding to subsequent technologies in same group. If “Auto-Invoke Efficiency Mode” is checked, program will begin “looking ahead” once the best available technology has a positive effective cost. “Back Fill Technology” directs program to apply the first technologies that appear in technology group whenever “jumping ahead” to subsequent technologies for some group of vehicles.

[49] Checking “Create Engine...” or “Create Transmission...” directs the program to “split” and engine or transmission under the indicated condition. Doing so limits the model’s tendency to “overshoot” CAFE standards. For example, checking “Create Engine if Cars Involved” directs the model to split an engine originally used in both cars and light trucks into a car version and a light truck version when applying technologies to that engine.

- Click the "Output Settings" tab. Specify default output path (recommend same as location of input files).

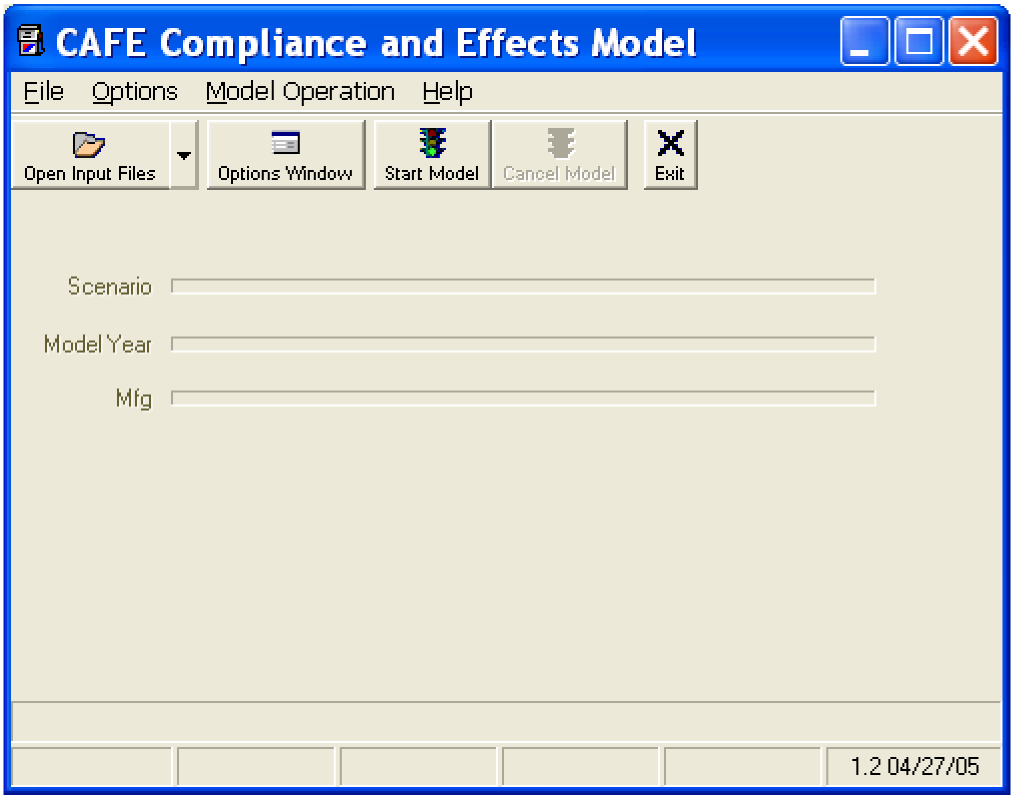
- Check "Hide Unused RCs" to omit cells in output files for unused regulatory classes.

- Check boxes for desired reports.

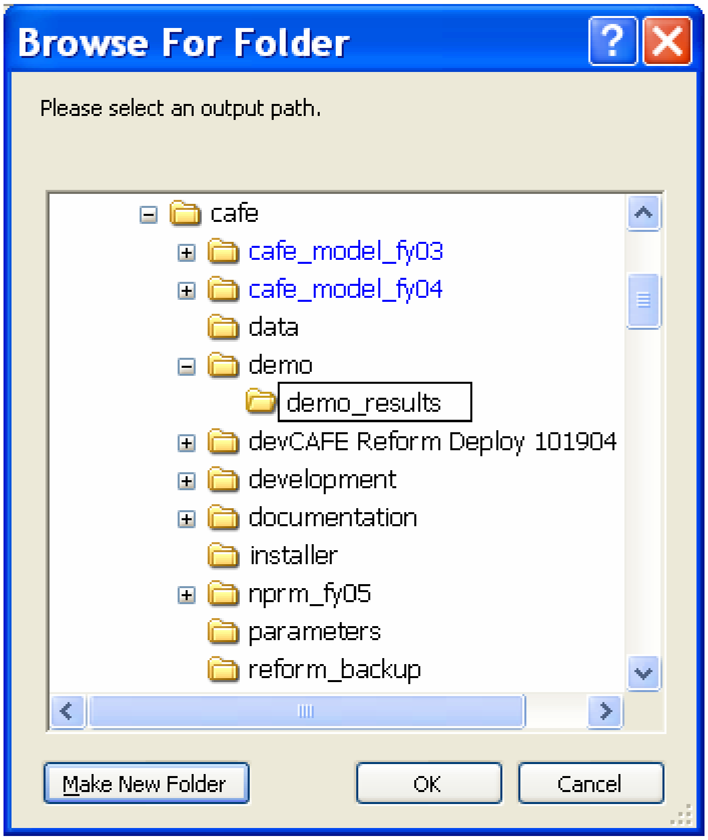


- If template files were included in the installed input files, click the "Templates" tab to specify their use and location. These files speed the production of output files.

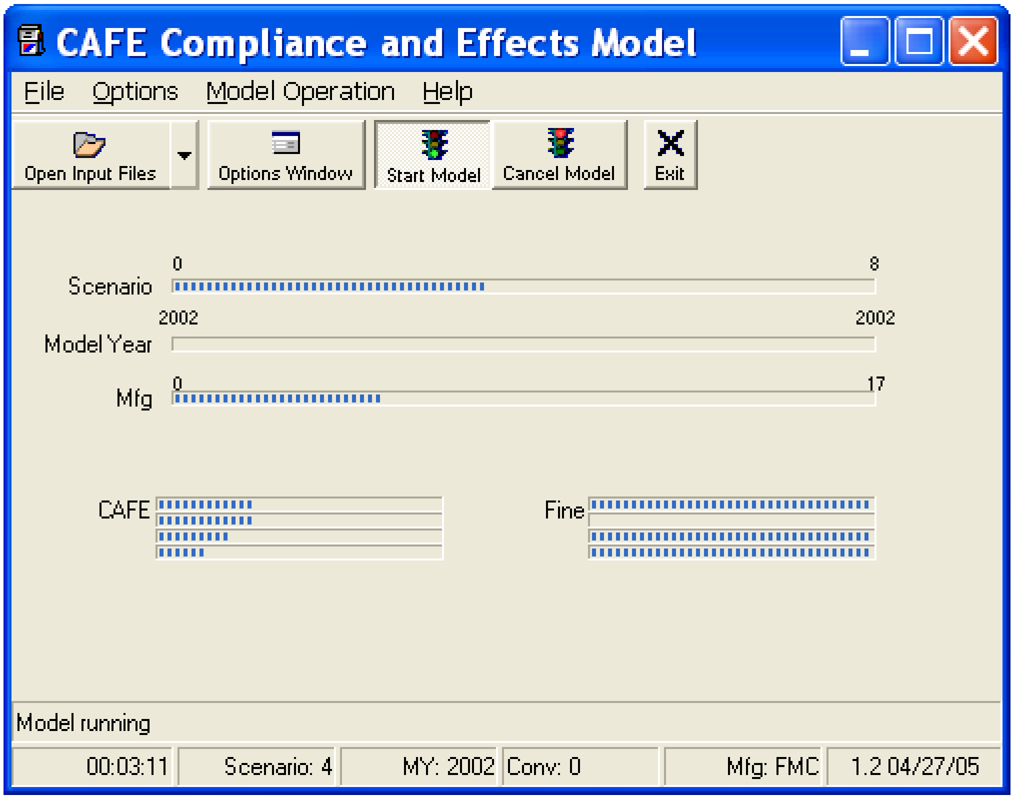
Step 5. Return to the main control window and click "Start Model", which should be "lit".



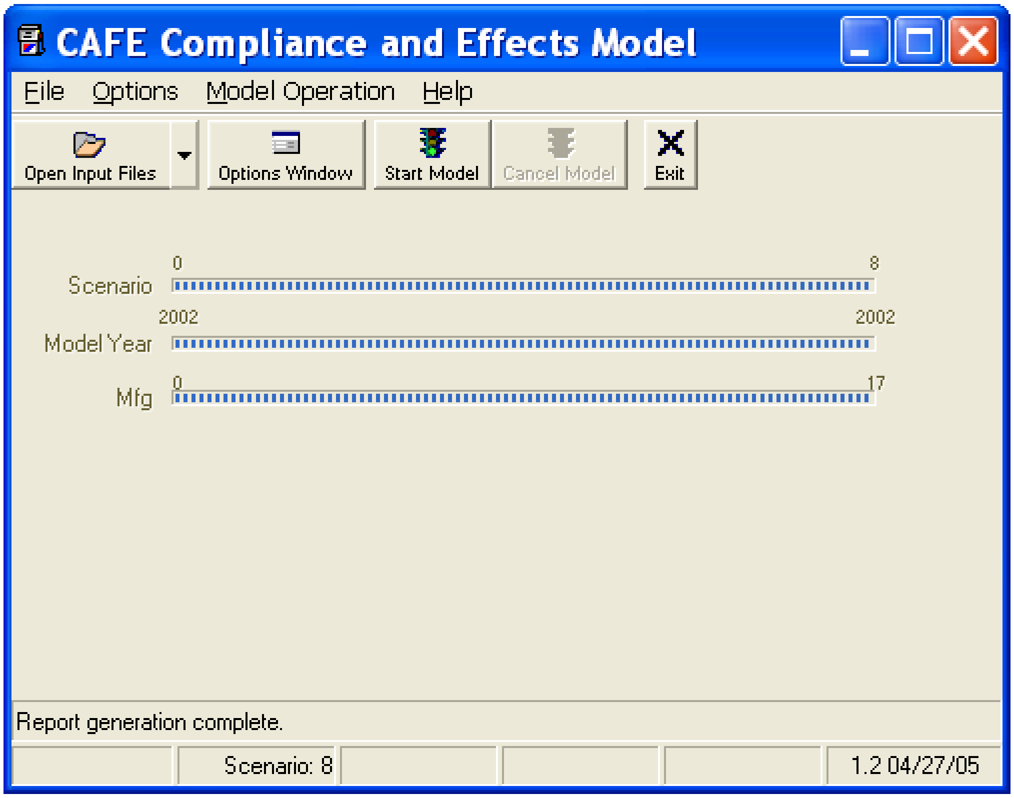
Step 6. Specify a location into which to place output files. Create a new folder if desired.



- While the compliance model is running, various status bars and other indicators are used to show progress. When running multiple CAFE scenarios, overall progress is most clearly indicated by the "Scenario" (topmost) status bar.



- The modeling and reporting have concluded when "Modeling complete" appears toward the bottom of the main control window.



Step 7. Click the "Exit" button on the main control window to close the program.

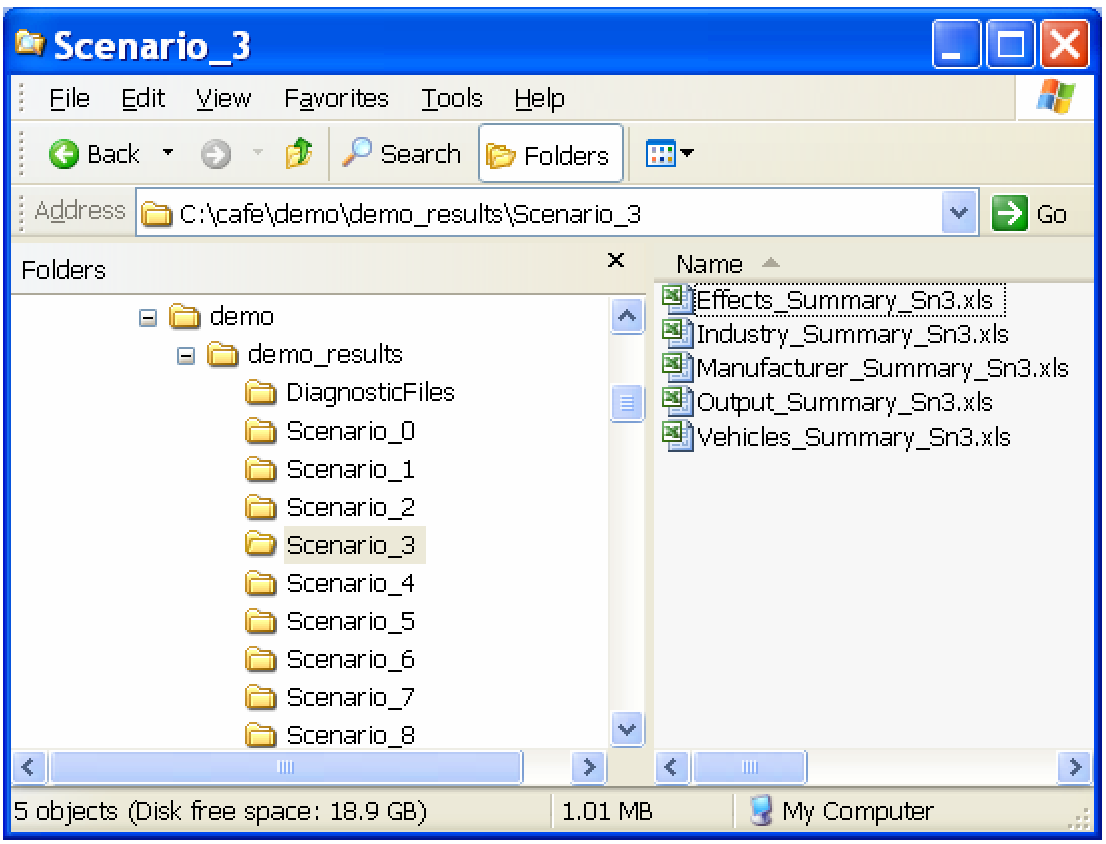
Step 9. View results by opening appropriate output files. The files are organized using one folder to hold results for included scenarios, which are numbered in order of appearance, starting at 0. The first scenario (0) is identified as the baseline scenario to which all others are compared. The following files are produced if specified in Step 4.

- *Effects_Summary_Sn*.xls*: Summary of energy, emissions effects.

- *Industry_Summary_Sn*.xls*: Industry-level summary of compliance model results.

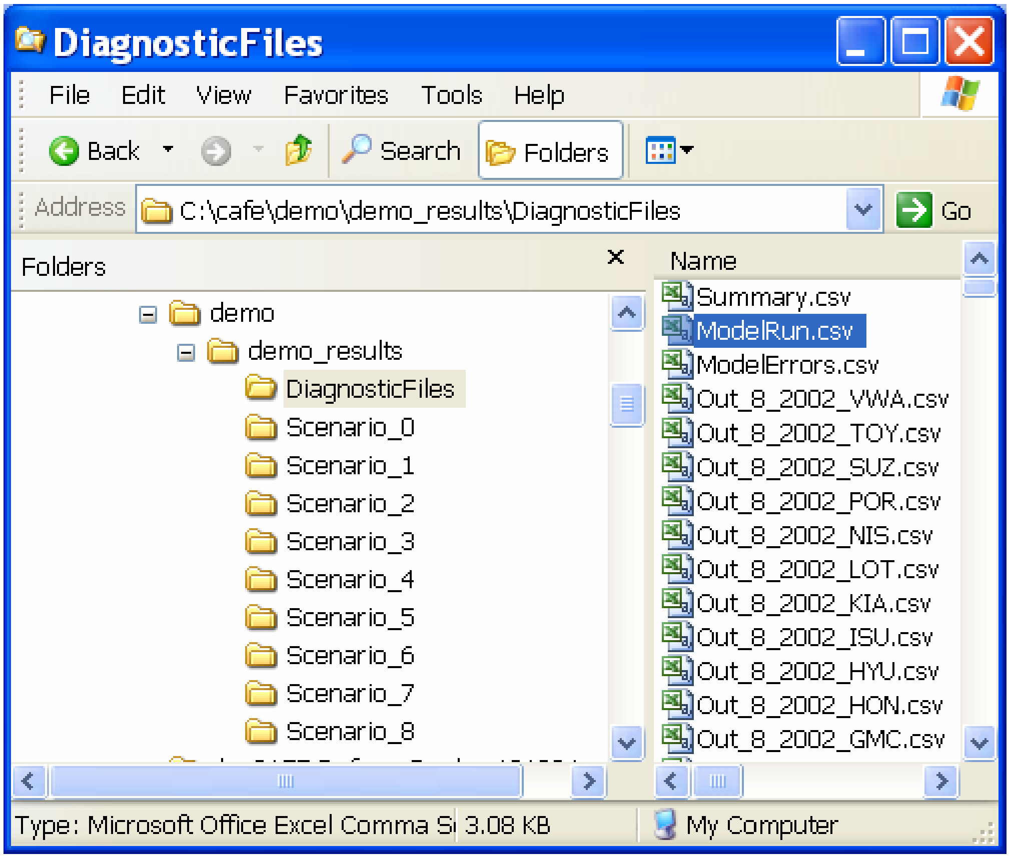
- *Manufacturer_Summary_Sn*.xls*: Manufacturer-level summary of compliance model results.

- *Vehicles_Summary_Sn*.xls*: Vehicle-level summary of compliance model results.



To protect confidential business information and otherwise protected information, the file defining the initial state of the fleet—*demo_market_data.xls*—contains fictitious entries for many fields. Therefore, when used with this file, the system will produce fictitious results. Though useful for diagnostic purposes, such results should be treated as otherwise meaningless, and should not be cited or released.

To review input files, model settings, and scenario descriptions, open *ModelRun.csv*, which is in the *DiagnosticFiles* folder.



Appendix C. Inputs

Overview

In addition to various operational settings that are, as discussed in Appendix B, specified by the user at the time the system is initiated, the system utilizes the three input files (all in Microsoft® Excel format) shown in Table C-.[50] As discussed in Appendix B, the user specifies the location of these files in the course of setting up a model run.

Table C-1. Input File Contents

Input File	**Contents**
Market Data (Vehicles Worksheet)	indexed list of vehicle models available during the study period, along with sales volumes, fuel economy levels, prices, other attributes, domestic labor utilization, references to specific engines and transmissions used, and optional settings related to technology applicability, designation as a passenger or nonpassenger automobile, and coverage of vehicles with GVWR above 8,500 pounds
Market Data (Engines Worksheet)	indexed list of engines available during the study period, along with various engine attributes and optional settings related to technology applicability
Market Data (Transmissions Worksheet)	indexed list of transmissions available during the study period, along with various engine attributes and optional settings related to technology applicability
Technologies	estimates of the availability, cost, and effectiveness of various technologies, specific to various vehicle categories identified by the NAS[51]
Scenarios	coverage, structure, and stringency of CAFE standards for scenarios to be simulated
Parameters	inputs used to calculate travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions, and economic externalities related to highway travel and petroleum consumption

[50] Until recently, the vehicle models, engines, and transmissions worksheet were contained in separate input files.

[51] add reference

Vehicle Models Worksheet

The vehicle models worksheet contains information regarding each vehicle model offered for sale during the study period. Each vehicle model is represented as a single row of input data. Table C-2 lists the different columns of information specified in the vehicle models file. To make the information readable, Table C-2 is presented vertically and divided into sections.

In the “General” category, the number, manufacturer, fuel economy, engine code, and transmission code must be specified for each vehicle model. The engine and transmission codes must refer to a valid engine and transmission, respectively, for the relevant manufacturer in the engine and transmission input files. Known or projected sales are specified in the “Sales” section for each model year in which the model is offered. Changes to a model—in particular any (*e.g.*, a different engine or transmission) that would affect fuel economy—are specified by creating a new row (effectively a new vehicle model) with the older model’s number in the “predecessor” field (discussed below).

Table C-2. Vehicle Models Worksheet

Category	Model Characteristic	Units	Definition/Notes
General	Number	integer	unique number assigned to each model
	Manufacturer	text	manufacturer abbreviation
	Model	text	name of model (i.e., Camry)
	Nameplate	text	vehicle nameplate (i.e., Camry Solara)
	Fuel Economy	mpg	weighted (FTP+highway) fuel economy
	Engine Code	integer	unique number assigned to each engine
	Transmission Code	integer	unique number assigned to each transmission
	Origin	text	classification as domestic or import (for light trucks, if classified in same manner as cars)
	General Notes	text	explanatory notes
Sales	MY2002	thousands	projected U.S. sales
	MY2003	thousands	projected U.S. sales
	MY2004	thousands	projected U.S. sales
	MY2005	thousands	projected U.S. sales
	MY2006	thousands	projected U.S. sales
	MY2007	thousands	projected U.S. sales
	MY2008	thousands	projected U.S. sales
	MY2009	thousands	projected U.S. sales
	MY2010	thousands	projected U.S. sales
	MY2011	thousands	projected U.S. sales
	MY2012	thousands	projected U.S. sales
	Sales Notes	text (up to 255 characters)	explanatory notes

Within the "Vehicle" category, it is important that each vehicle model's style, class, drive, overall length, overall width, curb weight, maximum seating capacity, and fuel capacity be specified. For any hybrid vehicle models, it is necessary to specify at least the type of hybridization.

Table C-2. Vehicle Models (continued)

Category	Model Characteristic	Units	Definition/Notes
Vehicle	Style	text	
	Class	text	vehicle class
	Structure	text	
	Drive	text	
	Final Drive Ratio	number	minimum gear ratio in differential (i.e., rear axle ratio for RWD vehicle)
	N/V	rpm/mph	average ratio of engine speed (rpm) divided by vehicle speed (mph) in top gear
	Front Axle Lubricant Viscosity	text	viscosity of rear axle lubricant
	Rear Axle Lubricant Viscosity	text	viscosity of front axle lubricant
	Overall Length	inches	per SAE J1100, L103 (July 2002)
	Overall Width	inches	per SAE J1100, W116 (July 2002)
	Overall Height	inches	per SAE J1100, H100 (July 2002)
	Wheelbase	inches	per SAE J1100, L101 (July 2002)
	Track Width (front)	inches	per SAE J1100, W101-1 (July 2002)
	Track Width (rear)	inches	per SAE J1100, W101-2 (July 2002)
	Ground Clearance	inches	per 49CFR523
	Front Axle Clearance	inches	per 49CFR523
	Rear Axle Clearance	inches	per 49CFR523
	Angle of Approach	degrees	per 49CFR523
	Breakover Angle	degrees	per 49CFR523
	Angle of Departure	degrees	per 49CFR523
	Height of Center of Gravity	inches	per NCAP
	Curb Weight	pounds	
	Test Weight	pounds	
	PAU Setting	horsepower	power absorption unit setting
	GVWR	pounds	Gross Vehicle Weight Rating; weight of loaded vehicle, including passengers and cargo
	Towing Capacity (standard)	pounds	standard amount of weight that may be pulled given standard vehicle equipment
	Towing Capacity (max)	pounds	maximum amount of weight that may be pulled given optional vehicle packages
	Payload	pounds	weight of cargo and occupants that may be carried in the vehicle
	Seating (min)	integer	number of usable seat belts after folding and removal of seats (where accomplished without special tools)
	Seating (max)	integer	number of usable seat belts before folding and removal of seats (where accomplished without special tools)
	Seating in First Row	integer	number of usable seat belts in first row before folding and removal of seats
	Cargo Vol. Behind First Row	cubic feet	per SAE J1100, Table 28 (July 2002)
	Seating in Second Row	integer	number of usable seat belts in second row before folding and removal of seats
	Second Row Flat Capability	text	does folding or removal of second row seats leave a flat surface flush with rearmost cargo area?
	Cargo Vol. Behind Second Row	cubic feet	per SAE J1100, Table 28 (July 2002)
	Seating in Third Row	integer	number of usable seat belts in third row before folding and removal of seats
	Third Row Flat Capability	text	does folding or removal of third row seats leave a flat surface flush with rearmost cargo area?
	Cargo Vol. Behind Third Row	cubic feet	per SAE J1100, Table 28 (July 2002)
	Enclosed Volume	cubic feet	total interior volume of vehicle
	Passenger Volume (standard)	cubic feet	passenger volume after folding and removal of seats (where accomplished without special tools)
	Passenger Volume (max)	cubic feet	passenger volume before folding and removal of seats (where accomplished without special tools)
	Cargo Volume Index	cubic feet	per SAE J1100, Table 28 (July 2002)
	Open Box Area Length	inches	per SAE J1100, L506 (July 2002)
	Open Box Area Width (min)	inches	per SAE J1100, W201 (July 2002)
	Open Box Area Width (max)	inches	per SAE J1100, W500 (July 2002)
	Open Box Area	square feet	product of (1) open box length and (2) average of min. and max. box width
	Open Box Height	inches	per SAE J1100, H503 (July 2002)
	Fuel Capacity	gallons	gallons of diesel fuel or gasoline; MJ (LHV) of other fuels (or chemical battery energy)
	Tire Rolling Resistance	number	Crr
	Frontal Area	square feet	
	Aerodynamic Drag Coefficient	number	Cd
	Vehicle Notes	text (up to 255 characters)	explanatory notes
Hybridization	Type	text	
	Voltage (or Pressure)	volts or psi	voltage of HEV battery or pressure of hydraulic hybrid accumulator
	Energy Storage Capacity	MJ	maximum energy (megajoules) stored in battery or accumulator
	Battery Type	text	
	Energy Transfer	text	transfer between brake and stored energy
	Braking Energy Recovery	percent	percentage of braking energy recovered and stored
	Share of Maximum Power	percent	percentage of maximum motive power provided by stored energy system
	Hybridization Notes	text (up to 255 characters)	explanatory notes

In the "Planning & Assembly" section, it is important that the number of any (single) predecessor to the current vehicle model be specified. The known or projected MSRP and average selling price should be specified in the corresponding sections for each model year in which the vehicle model is offered for sale.

Table C-2. Vehicle Models (continued)

Category	Model Characteristic	Units	Definition/Notes
Planning & Assembly	Predecessor	integer	number of model upon with current model is based
	Last Freshening	model year	
	Next Freshening	model year	
	Last Redesign	model year	
	Next Redesign	model year	
	U.S./Canadian Content	percent	overall percentage, by value, that originated in U.S. or Canada
	Final Assembly City	text	city of the final assembly point
	Final Assembly State	text	state of the final assembly point
	Final Assembly Country	text	country of the final assembly point
	Employment Hours per Vehicle	hours	hours of U.S. manufacturing employment per vehicle
	Planning & Assembly Notes	text (up to 255 characters)	explanatory notes
MSRP	MY2002	dollars (2003)	average MSRP
	MY2003	dollars (2003)	projected average MSRP
	MY2004	dollars (2003)	projected average MSRP
	MY2005	dollars (2003)	projected average MSRP
	MY2006	dollars (2003)	projected average MSRP
	MY2007	dollars (2003)	projected average MSRP
	MY2008	dollars (2003)	projected average MSRP
	MY2009	dollars (2003)	projected average MSRP
	MY2010	dollars (2003)	projected average MSRP
	MY2011	dollars (2003)	projected average MSRP
	MY2012	dollars (2003)	projected average MSRP
	MSRP Notes	text (up to 255 characters)	explanatory notes

Information in the "Emissions" section is currently optional. In the "LT Definition" section, values of "TRUE" and "FALSE" are used to indicate whether each vehicle model is classified as a light truck (*i.e.*, nonpassenger automobile) under the corresponding alternative definition, of which up to 5 are supported. For a given CAFE scenario, the choice of one of these alternatives (or the current definition) is specified in the compliance model parameters input file, which is discussed below. Similarly, the "HLT Definition" section is used to indicate whether a given vehicle model with a GVWR over 8,500 pounds is to be regulated under each of up to five corresponding cases. However, unlike the "LT Definition" field, this field may be left blank for any unaffected vehicle models.

The applicability of technologies considered on a vehicle model basis (as opposed, for example, to an engine basis) can be controlled for each vehicle model by using the "Technology Applicability Overrides". As discussed in Section III.B.1, the applicability of a given technology to a given vehicle is first tested by considering the choice of "technology path" specified in the technology input file (discussed below). However, if any overrides are specified in the vehicle models file, they will preempt the technology path.

Table C-2. Vehicle Models (continued)

Category	Model Characteristic	Units	Definition/Notes
Emissions	EPA Class	text	Tier 2 Class
	EPA Certification Bin	integer	Tier 2 Bin
	LEV Class	text	
	Emissions Notes	text (up to 255 characters)	explanatory notes
LT Definition	LTDFN1	boolean	definition as nonpassenger automobile under alternative definition #1
	LTDFN2	boolean	definition as nonpassenger automobile under alternative definition #2
	LTDFN3	boolean	definition as nonpassenger automobile under alternative definition #3
	LTDFN4	boolean	definition as nonpassenger automobile under alternative definition #4
	LTDFN5	boolean	definition as nonpassenger automobile under alternative definition #5
HLT Definition	HLTDFN1	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #1
	HLTDFN2	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #2
	HLTDFN3	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #3
	HLTDFN4	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #4
	HLTDFN5	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #5
Effects	Safety Class	text	classification per recent NHTSA report on safety
	MOBILE6 Class	text	classification per EPA MOBILE6 model
	% 2 DR Cars	percent	share of vehicle model with 2 or 3 doors
	Market Segment - VOLPE	text	not currently used
	Market Segment - Auto News	integer	coded market share per *2002 Automotive News Market Classifications*
Technology Applicability Overrides	ROLL	text	force system to "ALLOW" or "SKIP" low rolling resistance tires
	EPS	text	force system to "ALLOW" or "SKIP" electric power steering
	EAI	text	force system to "ALLOW" or "SKIP" engine accessory improvements
	AER	text	force system to "ALLOW" or "SKIP" aerodynamic drag reduction
	42V	text	force system to "ALLOW" or "SKIP" 42V electrical system
	ISG	text	force system to "ALLOW" or "SKIP" integrated starter/generator
	WGT	text	force system to "ALLOW" or "SKIP" weight reduction
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	

Engines Worksheet

Similar to the vehicle models input file, the engines input worksheet contains a list of all engines used in vehicle models offered for sale during the study period. For each manufacturer, the engine code is a unique number assigned to each such engine. This code is referenced in the engine code field of the vehicle models input file. For each engine, the engine code, manufacturer, fuel, cycle, number of cylinders, number of valves per cylinder, and horsepower must all be specified. As in the vehicle models worksheet, technology path overrides for any engine technology can be specified for any specific engine.

Table C-3. Engines Input Worksheet

Engine Characteristic	Units	Definition/Notes
Engine Code	integer	unique number assigned to each engine
Manufacturer	text	manufacturer abbreviation
Name	text	name of engine
Origin	text	country of origin
Fuel	text	most common fuel with which engine is compatible
Engine Oil Viscosity	text	
Cycle	text	combustion cycle
Air/Fuel Ratio	number	weighted (FTP+highway) air/fuel ratio (mass)
Fuel System	text	mechanism that delivers fuel to engine
Aspiration	text	
Valvetrain Design	text	
Valve Actuation/Timing	text	
Valve Lift	text	
Cylinders	integer	number of engine cylinders
Configuration	text	
Valves/Cylinder	integer	number of valves per cylinder
Deactivation	number	weighted (FTP+highway) aggregate degree of deactivation
Displacement	liters	total volume displaced by a piston in a single stroke
Compression Ratio (Min)	number	for fixed CR engines, should be identical to maximum CR
Compression Ratio (Max)	number	for fixed CR engines, should be identical to minimum CR
Horsepower	horsepower	maximum power (horsepower)
Torque	foot-pounds	maximum torque (foot-pounds)
Engine Notes	text (up to 255 characters)	explanatory notes
LUB	text	force system to "ALLOW" or "SKIP" low-friction lubricants
EFR	text	force system to "ALLOW" or "SKIP" engine friction reductoin
OHC	text	force system to "ALLOW" or "SKIP" 4-valve OHC
VVT	text	force system to "ALLOW" or "SKIP" variable valve timing
DISP	text	force system to "ALLOW" or "SKIP" cylinder deactivation
VVLT	text	force system to "ALLOW" or "SKIP" variable valve lift & timing
SUP	text	force system to "ALLOW" or "SKIP" supercharging & downsizing
CVA	text	force system to "ALLOW" or "SKIP" camless valve acuation
IVT	text	force system to "ALLOW" or "SKIP" intake valve throttling
VCR	text	force system to "ALLOW" or "SKIP" variable compression ratio

Transmissions Worksheet

Similar to the vehicle models and engines input worksheets, the transmissions input worksheet contains a list of all transmissions used in vehicle models offered for sale during the study period. For each manufacturer, the transmission code is a unique number assigned to each such transmission. This code is referenced in the transmission code field of the vehicle models input file. For each transmission, the transmission code, manufacturer, type, and control must all be specified. As in the vehicle models input worksheet, technology path overrides for any transmission technology can be specified for any specific transmission.

Table C-4. Transmissions Input File

Transmission Characteristic	Units	Definition/Notes
Transmission Code	integer	unique number assigned to each transmission
Manufacturer	text	manufacturer abbreviation
Name	text	name of transmission
Origin	text	country of origin
Type	text	
Number of Forward Gears	integer	
Control	text	ASMT would be coded as Type=C, Control=A
Logic	text	aggressivity of automatic shifting
Gear Ratio - 1st Gear	number	maximum gear ratio (e.g., first gear) in high gear range
Gear Ratio - 2nd Gear	number	
Gear Ratio - 3rd Gear	number	
Gear Ratio - 4th Gear	number	
Gear Ratio - 5th Gear	number	
Gear Ratio - 6th Gear	number	
Reverse Gear	number	minimum gear ratio (e.g., highest gear) in high gear range
TC Ratio	number	torque converter ratio
Axle Ratio	number	axle ratio
TC Lockup/Bypass	boolean	torque converter lockup or bypass
Transmission Fluid Specification	text	specification of automatic transmission fluid
Transmission Lubricant Viscosity	text	viscosity of manual transmission lubricant
Transmission Notes	text (up to 255 characters)	explanatory notes
5SP	text	forces system to "ALLOW" or "SKIP" 5-speed transmissions
6SP	text	forces system to "ALLOW" or "SKIP" 6-speed transmissions
ASL	text	forces system to "ALLOW" or "SKIP" aggressive shift logic
CVT	text	forces system to "ALLOW" or "SKIP" continuously variable transmissions
AST	text	forces system to "ALLOW" or "SKIP" automatically shifted clutch transmissions
ACVT	text	forces system to "ALLOW" or "SKIP" advanced CVTs
HEV	text	forces system to "ALLOW" or "SKIP" midrange hybridization

Taken together, the vehicle models, engine, and transmissions input files provide "initial state" historical and/or forecast data for the light vehicle fleet.

For system development and testing, we have assembled these three input files by integrating information from several sources of data regarding the MY2002 fleet. For vehicles already subject to CAFE regulations (*i.e.*, all passenger and nonpassenger automobiles with GVW ratings under 8,500 pounds), we began with a NHTSA database containing fuel economy levels, sales volumes, and basic vehicle, engine, and transmission characteristics. To this database, we added significant information from different commercial sources, including Wards, Automotive News, and Edmunds.com.[52]

[52] add specific references

Because NHTSA's database does not include information regarding vehicles with GVW ratings between 8,500 and 10,000 pounds, it was necessary to use other sources for all information. Two manufacturers provided basic data for such vehicles, including sales volumes and many key vehicle, engine, and transmission attributes.[53] For the other manufacturer selling such vehicles, we developed this type of basic information—in particular, sales volumes—by analyzing data purchased from Polk.[54] For vehicles in this GVWR range, we then added information from the above-mentioned sources.

[53] One of these manufacturers provided MY2003 data. Because other available data was for MY2002, we adjusted MY2003 sales data provided by this manufacturer by matching different vehicle models to vehicle models represented in data from Wards, and comparing MY2002 and MY2003 sales figures from Wards.

[54] add reference

[56] National Research Council, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, (Washington, D.C.: National Academy of Sciences, 2002), pp. 42-44.

Technologies

The technologies input file contains assumptions regarding the fuel consumption benefit, cost, applicability, and availability of different vehicle, engine, and transmission technologies during the study period. Input assumptions are specific to each of the following vehicle types: small SUVs, midsize SUVs, large SUVs, minivans, small pickups, large pickups, subcompact cars, compact cars, midsize cars, and large cars. The vehicle types and most of the technologies represented match those considered in a recent report by the National Academy of Sciences (NAS).[56] The report, prepared in response to a Congressional directive in the FY 2001 DOT Appropriations Act, included an examination of technologies that could be used to increase the fuel economy of new light duty vehicles. The NAS did not discuss all possible technologies, but rather a list of about two dozen specific technologies and groups of technologies. The NAS report has received extensive external review, and is considered to be a reasonably diverse and complete documentation on a range of technologies. Table C-5 shows sample technology assumptions for small SUVs:

Table C-5. Technologies Input File (Sample)

Small SUV	Variables					Path					
Technology	FC-Low	FC-High	Cost-Low	Cost-High	Year Avail.	Path1	Path2	Path3	Phase-in	kWeight	Abbr.
Low Friction Lubricants	1.00%	1.00%	$ 8.00	$ 11.00	2008	TRUE	TRUE	TRUE	25%		LUB
Improve Rolling Resistance	1.00%	1.50%	$ 15.00	$ 58.00	2008	TRUE	TRUE	TRUE	25%		ROLL
Low Drag Brakes	0.75%	1.25%	$ 15.00	$ 146.00	2008	TRUE	TRUE	TRUE	17%		LDB
Engine Friction Reduction	1.00%	5.00%	$ 36.00	$ 146.00	2008	TRUE	TRUE	TRUE	17%		EFR
Front Axle Disconnect (for 4WD)	1.50%	2.50%	$ 100.00	$ 110.00	2008				17%		FAD
Cylinder Deactivation	3.00%	6.00%	$ 116.00	$ 262.00	2008				17%		DISP
Multi-Valve, Overhead Camshaft	2.00%	5.00%	$ 109.00	$ 146.00	2008	TRUE	TRUE	TRUE	17%		OHC
Variable Valve Timing	2.00%	3.00%	$ 36.00	$ 146.00	2008	TRUE	TRUE	TRUE	17%		VVT
Electric Power Steering	1.50%	2.50%	$ 109.00	$ 156.00	2008		TRUE	TRUE	17%		EPS
Engine Accessory Improvement	1.00%	2.00%	$ 87.00	$ 116.00	2008	TRUE	TRUE	TRUE	25%		EAI
5-Speed Automatic Transmission	2.00%	3.00%	$ 73.00	$ 160.00	2008	TRUE			17%		5SP
6-Speed Automatic Transmission	1.00%	2.00%	$ 146.00	$ 291.00	2009				17%		6SP
Automatic Transmission w/ Aggressive Shift Logic	1.00%	3.00%	$ -	$ 73.00	2008				17%		ASL
Continuously Variable Transmission (CVT)	4.00%	8.00%	$ 146.00	$ 364.00	2008		TRUE	TRUE	17%		CVT
Automatic Shift Manual Transmission (AST/AMT)	3.00%	5.00%	$ 73.00	$ 291.00	2010				17%		AST
Aero Drag Reduction	1.00%	2.00%	$ -	$ 146.00	2009		TRUE	TRUE	17%		AER
Variable Valve Lift & Timing	1.00%	2.00%	$ 73.00	$ 218.00	2008		TRUE	TRUE	17%		VVLT
Spark Ignited Direct Injection (SIDI)	1.00%	3.00%	$ 200.00	$ 250.00	2008		TRUE	TRUE	3%		SIDI
Engine Supercharging & Downsizing	5.00%	7.00%	$ 364.00	$ 582.00	2008			TRUE	17%		SUP
42 Volt Electrical Systems	1.00%	2.00%	$ 73.00	$ 291.00	2008		TRUE	TRUE	17%		42V
Integrated Starter/Generator	4.00%	7.00%	$ 218.00	$ 364.00	2009		TRUE	TRUE	5%		ISG
Intake Valve Throttling	3.00%	6.00%	$ 218.00	$ 437.00	2010		TRUE		17%		IVT
Camless Valve Actuation	5.00%	10.00%	$ 291.00	$ 582.00	2010			TRUE	10%		CVA
Variable Compression Ratio	2.00%	6.00%	$ 218.00	$ 510.00	2010			TRUE	10%		VCR
Advanced CVT	0.00%	2.00%	$ 364.00	$ 874.00	2009				17%		ACVT
Dieselization	15.00%	20.00%	$ 1,000.00	$ 2,000.00	2010			TRUE	3%		DSL
Material Substitution (cost in $ per pound reduced)	0.60%	0.70%	$ 0.75	$ 0.75	2008	TRUE	TRUE	TRUE	17%	1.0%	MS1
Material Substitution (cost in $ per pound reduced)	0.60%	0.70%	$ 1.00	$ 1.00	2008		TRUE	TRUE	17%	1.0%	MS2
Material Substitution (cost in $ per pound reduced)	1.75%	2.10%	$ 1.25	$ 1.25	2008			TRUE	17%	3.0%	MS3
Material Substitution (cost in $ per pound increased)	-0.60%	-0.70%	$ 0.75	$ 0.75	2008				17%	-1.0%	MSX
Midrange Hybrid Vehicle	25.00%	35.00%	$ 3,000.00	$ 5,000.00	2010			TRUE	3%		HEV

Most of the technologies in Table C-5 are from the NAS report. We have also added low drag brakes, front axle disconnect, "Dieselization", hybridization (conversion to Diesel cycle engine and hybrid drivetrain, respectively) as technologies and used an incremental approach to considering material substitution. The NAS report did not project the use of Diesel engines and hybrid drivetrains because of uncertainties regarding costs. Notwithstanding these uncertainties, we accommodate these options in order to provide a basis for evaluating scenarios that include them.

With respect to materials substitution, the NAS estimated that a 5 percent weight reduction could be achieved at a constant cost of $210-350, reducing fuel consumption by 3-4%. In order to accommodate the possibility of smaller changes in materials (*e.g.*, resulting from changes in fewer and/or smaller components), and to account for the fact that constant percentage changes in weight imply greater absolute substitution of materials and therefore greater cost for heavier vehicles, we instead represent three levels of materials substitution as weight-reducing technologies. The relative reduction of vehicle weight at each level is specified in the k_{Weight} column as a percentage reduction of the vehicle's current curb weight. This approach is similar to that used by NEMS, and specifies cost in dollars per pound of reduction of vehicle weight. We also accommodate the possibility that materials substitution could be applied to <u>increase</u> vehicle weight, as doing so might appear as a logical compliance strategy under some weight-based CAFE systems.

For each technology, Table C-5 contains the following:

FC-Low:	low-end estimate of the incremental fuel consumption reduction
FC-High:	high-end estimate of the incremental fuel consumption reduction
Cost-Low:	low-end estimate of the incremental cost (RPE in 2003 dollars, or dollars/pound for material substitution)
Cost-High:	high-end estimate of the incremental cost (RPE in 2003 dollars, or dollars/pound for material substitution)
Year Avail:	first year the technology is available
Path:	inclusion on each of three "technology paths"[57]
Phase-In:	maximum incremental share of a manufacturer's fleet to which technology can be added in any single model year
kWeight:	relative change in curb weight (for material substitution only)
Abbr.:	technology abbreviation used in code and output files
Seq.:	sequence to follow when populating technology groups
TechType:	technology group into which to place technology

The structures for handling fuel consumption changes, costs, and technology path are all consistent with the NAS report. Because the NAS report considered the feasibility of higher CAFE levels at some unspecified point in the future, it did not directly address potential constraints on the rate at which technologies could penetrate the fleet. We have done so by including the year available and phase-in cap mentioned above. The example shown in Table C-5 specifies first year available of 2008 and a phase-in cap of 25% for cylinder deactivation. This constrains the compliance simulation model discussed in Section III.B.1 such that it does not begin considering applying cylinder deactivation until MY2007. Also, in the initial model year that the model attempts to apply cylinder deactivation to a given manufacturer's fleet, it stops

[57] Page 40 of the NAS report refers to these as "product development paths".

applying the technology if it has affected at least 25% that manufacturer's fleet. In the second year, it is allowed to apply cylinder deactivation to an additional 25%, and so on.

The technologies are organized into technology types specified by TechType field in the rightmost column shown by example in Table C-5. Each technology type is populated with specific technologies following the sequence indicated in the "Seq." column. For example, Table C-5 will cause the compliance simulation model to consider engine technologies in the following order: low-friction lubricants, engine friction reduction, multivalve overhead camshaft design, variable valve timing, cylinder deactivation, variable valve lift and timing, supercharging and downsizing, camless valve actuation, intake valve throttling, variable compression ratio, and Dieselization.

For system development and testing, we have developed technology files that, for the most part, define the same technology paths and use the same cost and fuel consumption estimates as in the NAS report. For each technology, we have specified an initial year of availability and a phase-in cap based on our expectations, taking into account relevant confidential information provided by manufacturers.

Our input assumptions for Dieselization, materials substitution, and hybridization also reflect our own expectations. Our review of MY2002 data indicates that Diesel engines typically involve a \$3,000-\$5,000 price premium and approximately a 35% reduction in the rate of fuel consumption. This is considerably higher than the NAS report's suggestion of a \$2,000-\$3,000 price premium. We reduce both cost and fuel consumption benefit estimates to appropriately treat Dieselization as an incremental improvement compared to a gasoline engine to which other technologies have already been applied.

We developed assumptions regarding the cost and effectiveness of materials substitution by considering EIA and NAS estimates. For AEO2004, EIA assumed the cost of materials substitution increases from \$0.40/pound to \$1.20/pound as the scale of weight reduction increases from 5% to 20%. The NAS report estimated a fixed cost of \$210-\$350, which is equivalent to approximately \$1.00/pound-\$2.00/pound depending on initial vehicle weight. The NAS's assumption that fuel consumption falls by about 0.6-0.8% for each 1% reduction in curb weight is similar to EIA's assumption that fuel economy increases by 0.67% for each such weight reduction.

We developed estimates of the incremental cost and effectiveness of hybrid drivetrains by considering relevant confidential information provided by some manufacturers. Although hybrid vehicles are currently available for sale, their incremental prices do not, in our estimation, reasonably reflect their costs.

Scenario Definition

Worksheets that begin “SCEN” are identified as CAFE program scenarios, which are defined in terms of the design and stringency of the CAFE program. The system numbers these scenarios 0,1,2,... based on their order of appearance. Scenario 0 (Scen0) is identified as the baseline scenario to which all others are compared. Each scenario defines the CAFE program as it relates to the following “regulatory classes”:

Table C-6. Regulatory Classes

Reg. Class	Includes
0	unregulated vehicles
1	passenger automobiles (domestic)
2	passenger automobiles (imported)
3(-10)	nonpassenger automobiles

Under the current system, all nonpassenger automobiles with GVW ratings below 8,500 pounds will be assigned to regulatory class 3. Regulatory classes 4-10 will all be unused. For systems involving subclasses of nonpassenger automobiles, some or all of these regulatory classes will be used. By default, regulatory class 0 includes vehicles with GVW ratings above 8,500 pounds. However, as discussed below, such vehicles can be selectively assigned to nonpassenger automobile regulatory classes.

Table C-7 shows an example of a CAFE scenario definition worksheet. The purpose of each of the named and bordered sections is as follows:

<u>Scenario Description</u>: a short name describing the key features of the scenario

<u>Passenger Automobile CAFE Standard</u>: numerical standard applicable in each model year

<u>Applicability of Light Truck Program</u>: LT Definition is used to specify change in definition of nonpassenger automobile (see Table C-2) and HLT Inclusion is used to specify scheme for including some vehicles with GVWRs over 8500 pounds (see Table C-2)

<u>LT Reg. Class Boundaries</u>: Attribute can be blank (for single-class systems), “A” for area-based systems, or “W” for curb-weight-based systems. Upper boundaries of each regulatory class appear below in either square feet or pounds, with “10,000” indicating the upper most regulatory class. All entries should be blank for systems covering nonpassenger automobiles as a single regulatory class. Flat standards applicable to each included class are specified in following section.

<u>Light Truck Flat Standard Value</u>: numerical standard applicable to each of regulatory classes 3-10 in each model year. All cells should be left blank for systems involving a functional CAFE standard.

<u>Trading Between LT Classes</u>: Specifying “Y” or “N” allows or disallows trading of CAFE credits between different classes of nonpassenger automobiles (but not between passenger and nonpassenger automobiles or between manufacturers). Future versions of

the system may allow the specification of a rate at which traded credits are to be discounted.

LT Functional Form: For CAFE systems subjecting nonpassenger automobiles to a functional standard, the appropriate type is indicated by entering the corresponding code from Table C-8. For example, entering "2" directs the compliance simulation model to apply a logistic weight-based standard. Functional CAFE standards are only accommodated for programs with all nonpassenger automobiles covered as a single regulatory class.

LT Functional Form Coefficients: If a functional standard from Table C-8 is specified above, contains corresponding coefficient values.

HLT Flat Standard: allows a separate standard to be specified for vehicles over 8,500 pounds GVWR

Transitional Flat Standard: allows a transitional standard to be provided as an alternative to an attribute-based CAFE standard (for light trucks only)

CAFE Fine Rate: specifies the rate at which civil penalties for noncompliance are incurred (*e.g.*, $55 per vehicle-mpg)

Table C-7. Scenario Definition Worksheet (Sample)

CAFE Scenario Definition Worksheet — Model Year

Scenario Description	conventional system with 22.2 mpg light truck standard

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Passenger Automobile CAFE Standard (mpg)	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5

		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Applicability of Light Truck Program	**LT Definition**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	HLT Inclusion	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Attribute	

	Reg. Class	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
LT Reg. Class Boundaries:	**3**														
	4														
(upper boundary of attribute)	**5**														
	6														
10,000 for highest class blank if not applicable	**7**														
	8														
	9														
	10														

	Reg. Class	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Light Truck Flat Standard Value (mpg)	**3**	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
	4														
	5														
	6														
	7														
	8														
	9														
	10														

		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Trading Between LT Classes	**Allowed?**														
	Discounting														

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
LT Std. Functional Form (Single Class Only)														

	Coefficient	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
LT Functional Form Coefficients (ignored for multiclass systems)	**A**														
	B														
	C														
	D														
	E														
	F														
	G														
	H														
	I														
	J														

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
HLT Flat Standard (mpg)														

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Transitional Flat Standard (mpg)														

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CAFE Fine Rate ($/mpg-vehicle)	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0

Table C-8. Functional CAFE Standard Specifications

Type	Description	Specification
1	"Fixed attribute" system based on MY2002 curb weights A: mpg	$STD_{MY} = \frac{A \times \sum_i SALES_{i,MY2002}}{\sum_i \left(SALES_{i,MY2002} \times CW_{i,MY2002} \right)}$
2	Logistic weight-based function A: mpg ("ceiling") B: mpg ("floor") C: pounds ("width") D: pounds ("midpoint')	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} + \left(\frac{1}{B} - \frac{1}{A} \right) \left(\frac{\exp\left(\frac{CW_{i,MY} - D}{C} \right)}{1 + \exp\left(\frac{CW_{i,MY} - D}{C} \right)} \right) \right] \right)}$
3	Exponential weight-based function A: mpg ("ceiling") B: mpg (should be >A) C: pounds (determines "height") note: if CWmin is the lowest possible weight, C must not exceed CWmin/(1-ln(B/A))	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{CW_{i,MY}}{C} \right) \right] \right)}$
4	Logistic area-based function A: mpg ("ceiling") B: mpg ("floor") C: square feet ("width") D: square feet ("midpoint")	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} + \left(\frac{1}{B} - \frac{1}{A} \right) \left(\frac{\exp\left(\frac{AREA_{i,MY} - D}{C} \right)}{1 + \exp\left(\frac{AREA_{i,MY} - D}{C} \right)} \right) \right] \right)}$
5	Exponential area-based function A: mpg ("ceiling") B: mpg (should be >A) C: sq. ft. (determines "height") note: if AREAmin is the lowest possible area, C must not exceed AREAmin/(1-ln(B/A))	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{AREA_{i,MY}}{C} \right) \right] \right)}$
6	Logistic weight- and area-based function A: mpg ("ceiling") B: mpg ("floor") C: pounds ("width") D: pounds ("midpoint") E: square feet ("width") F: square feet ("midpoint")	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} + \left(\frac{1}{B} - \frac{1}{A} \right) \left(\frac{\exp\left(\frac{CW_{i,MY} - D}{C} \right)}{1 + \exp\left(\frac{CW_{i,MY} - D}{C} \right)} \right) \left(\frac{\exp\left(\frac{AREA_{i,MY} - F}{E} \right)}{1 + \exp\left(\frac{AREA_{i,MY} - F}{E} \right)} \right) \right] \right)}$
7	Exponential weight- and area-based function A: mpg B: mpg C: pounds D: square feet note: select coefficients carefully	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{CW_{i,MY}}{C} - \frac{AREA_{i,MY}}{D} \right) \right] \right)}$
8	Weight-based function with "weight efficiency" credit A: mpg B: pounds C: dimensionless D: dimensionless E: pounds per square foot F: pounds	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(\frac{SALES_{i,MY}}{A} \left(\frac{CW_{i,MY}}{B} + C \right) \left(D - \frac{CW_{i,MY}}{E * AREA_{i,MY} - F} \right) \right)}$
9	Harmonically averaged targets TARGET: bin-specific "target" (mpg) (involves recasting RC3+ as "bins" that all exist with RC3)	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(\frac{SALES_{i,MY}}{TARGET_{i,MY}} \right)}$

[page intentionally blank]

Parameters

The benefits model parameters file contains a variety of input data and assumptions used to estimate various impacts of the simulated response of the industry to CAFE standards. The file contains a series of worksheets, the contents of which are summarized below.

"General" Parameters

The "general" parameters worksheet contains a few input assumptions used when calculating the "effective cost" of technologies using (1.1). These include the discount rate, payback period, and fuel economy shortfall to use when calculating the value of reductions in fuel consumption.[58]

Table C-10. "General" Parameters (Sample)

Discount Rate	7.0%
Payback Period	5
FE Shortfall	15%
Kf	$ 55.00

[58] Currently, the "general" parameters worksheet also specifies the fine rate. We are updating the code to exclusively use the values specified in scenario worksheets, as indicated by Table C-7.

MY2002 Curb Weights

If a "fixed attribute" system based on MY2002 curb weights (see Table C-8) is selected (see "LT Std. Functional Form" in Table C-7), data regarding manufacturer-specific average nonpassenger automobile curb weights is required. The "MY02LTWeight" worksheet, shown in Table C-11, contains this information. For those manufacturers (*e.g.*, Daewoo, or DAE) that did not produce nonpassenger vehicles in MY2002, the system applies the industry-wide average value of 4,329 pounds if the vehicles input files indicates that the same manufacturers will introduce such vehicles in subsequent model years.

Table C-11. MY2002 Curb Weights

Mfr. Code	Weight
BMW	4,554
DAE	4,329
DCC	4,272
FIA	4,329
FMC	4,294
FUJ	4,329
GMC	4,692
HON	3,706
HYU	3,630
ISU	3,988
KIA	4,023
LOT	4,329
NIS	3,983
POR	4,329
SUZ	3,510
TOY	3,991
VWA	4,272

Willingness to Pay Fines

Specifies whether or not to assume each manufacturer is willing to pay CAFE fines if doing so would be less expensive than applying technology. Table C-12 shows sample assumptions in which BMW, Fiat, Lotus, Porsche, and Volkswagen are all assumed to be willing to pay fines.

Table C-12. Manufacturers' Willingness to Pay CAFE Fines

Willingness to Pay CAFE Fines

Mfr. Code	2002	2003	2004
BMW	Y	Y	Y
DAE	N	N	N
DCC	N	N	N
FIA	Y	Y	Y
FMC	N	N	N
FUJ	N	N	N
GMC	N	N	N
HON	N	N	N
HYU	N	N	N
ISU	N	N	N
KIA	N	N	N
LOT	Y	Y	Y
NIS	N	N	N
POR	Y	Y	Y
SUZ	N	N	N
TOY	N	N	N
VWA	Y	Y	Y

Vehicle Age Data

The "Vehicle Age Data" worksheet contains age-specific (*i.e.*, vintage-specific) estimates of the survival rate and annual accumulated mileage applicable to different vehicle categories.

Table C-16. Vehicle Age Data

Category	Model Characteristic	Units	Definition/Notes	Source
Vehicle Age Data	Survival Rate	proportion	Proportion of original vehicle sales that remain in service by vehicle age (year 0 to 25)	U.S. Environmental Protection Agency, Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage Accumulation Rates and Projected Vehicle Counts for Use in MOBILE6, EPA420-P-99-011, April 1999, http://www.epa.gov/otaq/models/mobile6/r01047.pdf, Appendix B, Table 4-5, p. 45.
	Average Annual Miles Driven	average miles per vehicle per year	Average annual miles driven by surviving vehicles by vehicle age (year 0 to 25)	

Separate survival fractions are used for automobiles and light trucks These measure the proportion of vehicles originally produced during a model year that remain in service at each age (up to 25 years for automobiles and 30 years for light trucks), by which time only a small fraction typically remain in service. The survival rates used in this analysis were estimated by NHTSA staff using R.L. Polk National Vehicle Population Profile data for 1999-2004, as described in *Vehicle Survivability and Travel Mileage Schedules*, Office of Regulatory Analysis and Evaluation, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, January 2005.

The measures of annual miles driven per vehicle for light-duty vehicles used in our model were estimated using equations fitted to data on estimated annual utilization of a sample of more than 50,000 household vehicles obtained from the Federal Highway Administration's *2001 National Household Travel Survey*.[62] Separate estimates of average annual use at different ages were developed for automobiles and three types of light trucks: pickups, vans, and sport/utility vehicles. Light truck models are assigned the appropriate schedule of annual mileage by age.

[62] See http://nhts.ornl.gov/2001/html_files/introduction.shtml .

Fuel Properties

The "Fuel Properties" worksheet contains estimates of the physical properties of gasoline and diesel fuel, as well as certain assumptions about the effects of reduced fuel use on different sources of petroleum feedstocks and on imports of refined fuels. These fuel properties and assumptions about the response of petroleum markets to reduced fuel use are used to calculatethe changes in vehicular carbon dioxide emissions as well as in "upstream" emissions (from petroleum extraction and refining and from fuel storage and distribution) that are likely to result from reduced motor fuel use.

Table C-17. Fuel Properties

Category	Model Characteristic	Units	Definition/Notes	Source
Fuel Properties	Energy Density	BTU/gal	Amount of energy stored in a given system or region of space per unit volume. Varies by fuel type.	Wang, Michael, The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model: Version 1.5 Technical Report, Argonne National Laboratory, August 1999, Table 3.3, p. 25 (http://greet.anl.gov/pdfs/esd_3v1.pdf).
	Mass Density	grams/gal	Mass per unit volume. Varies by fuel type.	
	Carbon Content	percent by weight	Average share of carbon in fuel. Varies by fuel type.	
	Sulfur Content	ppm by weight	Average share of sulfur in fuel. Varies by fuel type.	
	Share of Base Case Fuel Use Imported as Refined Fuel	percent	Varies by fuel type	Energy Information Administration, Annual Energy Outlook 2003, Tables 1, 2, and 117; and Volpe assumptions
	Share of Base Case Fuel Use Refined within U.S.	percent	Varies by fuel type	
	Share Refined from Domestic Crude	percent	Varies by fuel type	
	Share Refined from Imported Crude	percent	Varies by fuel type	
	Share of Fuel Savings Leading to Lower Fuel Imports	percent	Varies by fuel type	
	Share of Fuel Savings Leading to Reduced Domestic Fuel Refining	percent	Varies by fuel type	
	Share of Reduced Domestic Refining from Domestic Crude	percent	Varies by fuel type	
	Share of Reduced Domestic Refining from Imported Crude	percent	Varies by fuel type	
	Assumed Fuel Mix	percent	Estimated share of total fuel consumption by fuel type	USEPA, Regulatory Impact Analysis for Tier 2 Emissions Standard, Table 19, p. 42; and estimate supplied by Ford Motor Company in comments on proposed 2005-07 Light Truck CAFE Rule

Energy density, mass density, carbon content, and sulfur content for different types of gasoline and for diesel were obtained from documentation describing the development of Argonne National Laboratory's GREET vehicel energy use and emissions model.[63]Fuel and crude petroleum import assumptions were calculated from Energy Information Administration, *Annual Energy Outlook 2003*, Tables 1, 2, and 117, and Volpe assumptions developed from discussions with Department of Energy staff.

The assumed mix of different types of gasoline used by light-duty vehicles was calculated from U.S. EPA, *Regulatory Impact Analysis for Tier 2 Emissions Standard*, Table 19, p. 42, and estimates supplied by the Ford Motor Company in comments on proposed 2005-07 Light Truck CAFE Rule. The mix of gasoline and diesel use was determined from sales volumes and fuel economy levels for light-duty vehicle models designed to operate on each fuel.

[63] Wang, Michael, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model: Version 1.5 Technical Report*, Argonne National Laboratory, August 1999, Table 3.3, p. 25 (http://greet.anl.gov/pdfs/esd_3v1.pdf).

Upstream Emissions

The "Upstream Emissions" worksheet contains emission factors for greenhouse gas and criteria pollutant emissions from petroleum extraction and transportation, and from fuel refining, storage, and distribution. These emission factors were calculated using emission rates derived from Argonne National Laboratories' GREET model..[64]

Table C-18. Upstream Emissions

Category	Model Characteristic	Units	Definition/Notes	Source
Upstream Emissions	Total Emissions by Petroleum Extraction	grams/million BTU	Varies by pollutant and fuel type	Argonne National Laboratory, The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, version 1.6, June 2001, Near-Term Output: Petroleum Fuels
	Total Emissions by Petroleum Transportation	grams/million BTU	Varies by pollutant and fuel type	
	Total Emissions by Petroleum Refining	grams/million BTU	Varies by pollutant and fuel type	
	Total Emissions by Refined Fuel Transportaion, Storage, and Delivery	grams/million BTU	Varies by pollutant and fuel type	
	Emissions in Urban Areas by Petroleum Extraction	grams/million BTU	Varies by pollutant and fuel type	
	Emissions in Urban Areas by Petroleum Transportation	grams/million BTU	Varies by pollutant and fuel type	
	Emissions in Urban Areas by Petroleum Refining	grams/million BTU	Varies by pollutant and fuel type	
	Emissions in Urban Areas by Refined Fuel Transportaion, Storage, and Delivery	grams/million BTU	Varies by pollutant and fuel type	

Fleet Parameters

The "Fleet Parameters" worksheet contains information used to assign vehicles to MOBILE6 classes for purposes of estimating tailpipe emissions of criterial pollutants, and to account for the gap between test and actual on-road fuel economy when calculating changes in fuel consumption. .

Table C-19. Fleet Parameters

Category	Model Characteristic	Units	Definition/Notes	Source
Fleet Parameters	% of Calendar $Year_{t-1}$ Sales that are Model $Year_t$ Vehicles	percent	THIS VALUE NOT USED IN CURRENT ANALYSIS	Volpe analysis of monthly sales patterns for new vehicles of model years 2002 and 2003 reported in Automotive News.
	% of Calendar $Year_t$ Sales that are Model $Year_t$ Vehicles	percent	THIS VALUE NOT USED IN CURRENT ANALYSIS	
	% of Calendar $Year_{t+1}$ Sales that are Model $Year_t$ Vehicles	percent	THIS VALUE NOT USED IN CURRENT ANALYSIS	
	% of Light Trucks under 6,000 lbs. GVWR consisting of MOBILE6 Class LDGT1	percent	Varies by calendar year.	Calculated from MOBILE6 fleet registration fractions for future calendar years.
	% of Light Trucks under 6,000 lbs. GVWR consisting of MOBILE6 Class LDGT2	percent	Varies by calendar year.	
	% of Light Trucks under 6,000 lbs. GVWR consisting of MOBILE6 Class LDDT12	percent	Varies by calendar year.	
	% of Light Trucks 6,001-8,500 lbs. GVWR consisting of MOBILE6 Class LDGT3	percent	Varies by calendar year.	
	% of Light Trucks 6,001-8,500 lbs. GVWR consisting of MOBILE6 Class LDGT4	percent	Varies by calendar year.	
	% of Light Trucks 6,001-8,500 lbs. GVWR consisting of MOBILE6 Class LDDT34	percent	Varies by calendar year.	
	Gap between Test and On-Road MPG	percent	Adjustment to reflect the expected size of the fuel economy "gap" between test condition fuel economy performance and on-road fuel economy performance	EPA/OTAQ estimate
	Average Fuel Tank Capacity	gallons	Varies by vehicle type.	Volpe calculation

Actual fuel economy levels achieved by vehicles in on-road driving falls significantly short of the level measured by U.S. EPA under test conditions. The actual fuel economy performance of each model year's vehicles is adjusted to reflect the expected size of this fuel economy "gap" in future calendar years.

[64] Argonne National Laboratories, *Development and Use of GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies(June 2001),* available at http://www.transportation.anl.gov/software/GREET/publications.html#intro

Economic Values

The "Economic Values" worksheet contains an estimate of the magnitude of the "rebound effect", as well as the rates used to compute the economic value of various direct and indirect impacts of CAFE standards, and the discount rate to apply when calculating present value.

Table C-20. Economic Values

Category	Model Characteristic	Units	Definition/Notes	Source
Economic Values	Rebound Effect	percent	Increase in the annual use of vehicle models in response to the lower per-mile cost of driving a more fuel-efficient vehicle	Various
	Discount Rate Applied to Future Benefits	percent per year		Office of Management and Budget, office of Information and Regulatory Analysis.
	Monopsony Component Economic Costs of Oil Imports	$/gallon (converted from original estimate in $/BBL)	Demand cost for imported oil; increasing domestic petroleum demand that is met through higher oil imports can cause the world price of oil to rise, and conversely that declining imports can reduce the world price of oil. Determined by a complex set of factors including the relative importance of U.S. imports in the world oil market, and the sensitivity of petroleum supply and demand to its world price among other participants in the international oil market	Leiby et al.
	Price Shock Component of Economic Costs of Oil Imports	$/gallon (converted from original estimate in $/BBL)	Expected value of costs to U.S. economy from reduction in potential output resulting from risk of significant increases in world petroleum price. Includes costs resulting from inefficiencies in resource use caused by incomplete adjustments to industry output levels and mixes of production input when world oil price changes rapidly.	
	Military Security Component of Economic Costs of Oil Imports	$/gallon (converted from original estimate in $/BBL)	Costs to taxpayers for maintaining a military presence to secure the supply of oil imports from potentially unstable regions of the world and protect the nation against their interruption	
	Economic Costs of Oil Imports	$/gallon	Sum of monopsony, price shock, and military security components	Calculated
	Congestion Costs from Additional Vehicle Use Due to "Rebound" Effect	$/vehicle-mile	Estimates intended to represent costs per vehicle-mile of increased travel compared to approximately current levels, assuming current distribution of travel by hours of the day and facility types.	Federal Highway Administration, 1997 Highway Cost Allocation Study, T. V-23
	Accidents Costs from Additional Vehicle Use Due to "Rebound" Effect	$/vehicle-mile		
	Noise Costs from Additional Vehicle Use Due to "Rebound" Effect	$/vehicle-mile		
	External Costs from Additional Vehicle Use Due to "Rebound" Effect	$/vehicle-mile	Sum of congestion, accidents, and noise costs	Calculated
	Carbon Monoxide Emission Costs	$/ton		McCubbin & DeLucchi
	Volatile Organic Compound Emission Costs	$/ton		OMB (1998), p. 72
	Nitrogen Oxide Emission Costs	$/ton		
	Particulate Matter Emission Costs	$/ton		
	Sulfur Dioxide Emission Costs	$/ton		
	Carbon Emission Costs	$/metric ton		
	Carbon Dioxide Emission Costs	$/metric ton		Volpe estimate
	Value of Travel Time per Person	$/hour		
	Average Vehicle Occupancy	double		USDOT Guidance
	Value of Travel Time per Vehicle	$/hour		NPTS

By reducing the cost of gasoline per mile driven, tighter CAFE standards can result in a slight increase in annual miles driven per vehicle. This increase in the annual number of miles each vehicle is driven, referred to as the "rebound effect," also produces a corresponding increase in the *total* number of miles driven by vehicles of each model year during each calendar year they remain in the fleet. The magnitude of the rebound effect from higher fuel economy standards is equal to the negative of the elasticity of vehicle use (measured either per vehicle or for an entire vehicle fleet) with respect to either fuel cost per mile driven (equal to fuel price per gallon divided by miles per gallon) or fuel efficiency itself. (This elasticity has a negative value, so the rebound effect is expressed as a positive value.) Most recent estimates of the magnitude of the rebound effect for light-duty vehicles fall in the relatively narrow range of 10% to 20%, which imply that increasing vehicle use will offset 10-20% of the fuel savings resulting directly from an improvement in fuel economy.[65]

Our model employs the annual discount rate of 7% recommended for evaluation of proposed regulations by the White House Office of Management and Budget's Office of Information and Regulatory Affairs.

Importing petroleum into the United States is widely believed to impose significant costs on households and businesses that are not reflected in the market price for imported oil, and thus are not borne by consumers of refined petroleum products. These costs include three components: (1) higher costs for oil imports resulting from the combined effect of U.S. import demand and OPEC market power on the world oil price; (2) the risk of reductions in U.S. economic output and disruption of the domestic economy caused by sudden reductions in the supply of imported oil; and (3) costs for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the Strategic Petroleum Reserve (SPR) to cushion against price increases. By reducing domestic demand for gasoline, tighter CAFE standards may reduce petroleum imports, thus lowering some or all of these external or social costs to the U.S. economy from importing oil.

Empirical estimates of the first of these three components of the economic cost of importing additional petroleum into the U.S. vary widely. A detailed analysis by Leiby *et al.* (1997) estimated a range of values for this cost corresponding to approximately $1.50-3.50 per barrel in today's terms.[66] Using the midpoint of this range, reducing the level of U.S. oil imports would result in "social" cost savings to the U.S. economy of approximately $2.50 per barrel beyond the direct savings in gasoline costs. This figure is equivalent to about $0.061 per gallon of gasoline saved as a consequence of more stringent CAFE regulation.

Leiby *et al.* also estimate that under reasonable assumptions about the probability that import supplies will be disrupted to varying degrees in the future, the second component of the social cost of oil imports ranges from slightly under $1.00 to approximately $3.00 per additional barrel of oil imported by the U.S. Within this range, an estimate of approximately $2.00 per barrel seems most appropriate, which implies that reductions in the level of oil imports resulting from tighter light truck CAFE standards would reduce disruption costs by about $0.045 per gallon of gasoline saved. This and other studies argue that the cost of maintaining a U.S. military presence

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[65] Recent estimates of the rebound effect resulting from higher fuel economy standards for light-duty vehicles indicate that a 10% reduction in fuel costs per mile results in a 1-2% increase in the number of miles driven. These values are derived from statistical estimates of the elasticity of miles driven per vehicle with respect to fuel cost per mile that range from approximately –0.10 to –0.20; see for example Greene, David L., "Vehicle Use and Fuel Economy: How Big is the Rebound Effect?" *The Energy Journal*, 13:1 (1992), 117-143; Greene, David L., James R. Kahn, and Robert C. Gibson, "Fuel Economy Rebound Effect for Household Vehicles," *The Energy Journal*, 20:3 (1999), 1-31; Jones, Clifton T., "Another Look at U.S. Passenger Vehicle Use and the 'Rebound' Effect from Improved Fuel Efficiency, *The Energy Journal*, 14:4 (1993), 99-110; and Goldberg, Pinelopi Koujianou, "The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.," *The Journal of Industrial Economics*, 46:1 (1998), 1-33. This study employs the midpoint of that range to estimate the rebound effect from tightening CAFE standards for light-duty trucks.

[66] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs*, ORNL-6851, Oak Ridge National Laboratory, November 1, 1997.

in oil-producing regions of the world and in stocking the the SPR are unlikely to vary in response to fluctuations in oil imports of the magnitude likely to result from changes in CAFE standards. Thus we assume that no savings in these costs are likely to be among the benefits of stricter fuel economy regulation.

Our analysis uses the Federal Highway Administration's estimates of the costs of the incremental (or "marginal") costs of added traffic congestion, accidents, and vehicle noise resulting from increased vehicle travel to estimate the increased external costs caused by added light truck use resulting from the rebound effect.[67] These estimates incorporate adjustments of current or baseline congestion and accident costs that are intended to reflect the traffic conditions under which additional driving is likely to take place, as well as its likely effects on both the frequency and severity of motor vehicle accidents. The FHWA estimates of these costs agree closely with other recent estimates of external costs from light-duty vehicle use.[68]

Estimates of damage costs for criteria pollutant emissions estimates were derived by the White House Office of Management and Budget's Office of Information and Regulatory Affairs from values used in recent U.S. EPA analyses of regulations intended to reduce various sources of these emissions.[69] Our model employs these estimates to calculate the increased health and property damage costs caused by added emissions of air pollutants and their chemical precursors resulting from "rebound effect" travel. Because of the extremely wide range of estimates for both damage and control costs for carbon emissions that have been reported in recent research, we do not do not attempt to estimate an economic value for reductions in carbon emissions from gasoline refining or use.

We assume that each refueling cycle requires 10 minutes, and we apply the current U.S. DOT estimates of the value of travel time and average vehicle occupancy to estimate the value of the annual time savings to drivers and passengers resulting from less frequent refueling. These values are reported in *The Value of Travel Time: Departmental Guidance for Conducting Economic Evaluations*, Office of the Assistant Secretary for Transportation Policy, April 9, 1997, and *Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis*, Office of the Assistant Secretary for Transportation Policy, February 11, 2003.[70]

Forecast Data

The "Forecast Data" worksheet contains exogenous forecasts of total long-term automobile and light truck sales. It also contains estimates of future fuel prices, which are used when calculating pre-tax fuel outlays and fuel tax revenues.

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[67] These estimates were developed by FHWA for use in its recent study of highway costs for different classes of vehicles; see Federal Highway Administration, 1997 Highway Cost Allocation Study, T. V-23.

[68] For example, see Ian W.H. Parry and Kenneth A. Small, "Does Britain or the U.S. Have the Right Gasoline Tax?" Discussion Paper 02-12, Resources for the Future, March 2002, pp. 19 and Table 1.

[69] *Progress in Regulatory Reform: 2004 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, http://www.whitehouse.gov/omb/inforeg/2004_cb_final.pdf

[70] See http://ostpxweb.dot.gov/reports.

Table C-21. Forecast Data

Category	Model Characteristic	Units	Definition/Notes	Source
Forecast Data	New Automobile Sales	thousands	Varies by fuel type	AEO 2003, Table 45
Forecast Data	New Light Truck Sales	thousands	Varies by fuel type	AEO 2003, Table 45
Forecast Data	Automobile EPA Fuel Economy Rating	mpg	THIS VALUE NOT USED IN CURRENT ANALYSIS	AEO 2003, Table 49
Forecast Data	Light Truck EPA Fuel Economy Rating	mpg	THIS VALUE NOT USED IN CURRENT ANALYSIS	AEO 2003, Table 49
Forecast Data	Automobile Ratio: On-Road to EPA Test	double	THIS VALUE NOT USED IN CURRENT ANALYSIS	AEO 2003, Table 49
Forecast Data	Light Truck Ratio: On-Road to EPA Test	double	THIS VALUE NOT USED IN CURRENT ANALYSIS	AEO 2003, Table 49
Forecast Data	Retail Fuel Price	2001 $/gallon	Varies by fuel type	AEO 2003, Table 12
Forecast Data	Federal Fuel Tax	2001 $/gallon	Varies by fuel type	FHWA Highway Statistics, Tables FE-21B and MF-121T
Forecast Data	Average State Fuel Tax	2001 $/gallon	Varies by fuel type	FHWA Highway Statistics, Tables FE-21B and MF-121T
Forecast Data	Total Fuel Tax	2001 $/gallon	Sum of federal fuel tax and average state fuel tax. Varies by fuel type	Calculated
Forecast Data	Pre-Tax Fuel Price	2001 $/gallon	Difference between retail fuel price and total fuel tax. Varies by fuel type	Calculated

Forecasts of total sales of new light-duty vehicles were obtained from the Energy Information Administration's (EIA) *Annual Energy Outlook 2005 (AEO 2005),* a standard government reference for forecasts of energy consumption and its determinants in different sectors of the U.S. economy.[71]

The economic value to society of the annual fuel savings resulting from stricter CAFE standards is assessed by applying the Energy Information Administration's *Annual Energy Outlook 2005 (AEO 2005)* forecast of future fuel prices excluding federal and state taxes to each year's estimated fuel savings.[72] Current Federal and average state taxes on gasoline and diesel are obtained from the Federal Highway Administration's Highway Statistics publication, and are assumed to remain fixed in constant-dollar terms at their current levels over the expected lifetimes of the vehicle model years analyzed in the model.[73]

[71] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2005*, Table 45,. http://www.eia.doe.gov/oiaf/aeo/supplement/sup_tran.xls

[72] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2005*, Table 12, http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_12.xls

[73] Federal Highway Administration, Highway Statistics 2003, Tablw MF121T, http://www.fhwa.dot.gov/policy/ohim/hs03/htm/mf121t.htm

Vehicular Criteria Pollutant Emission Factors

Emission factors (all in grams per mile and specific to both vehicle model year and age) for three fuel types (gasoline, reformulated gasoline, and Diesel) and five pollutants (CO, VOC, NO_X, $PM_{2.5}$, and SO_2) are contained in a series of fifteen worksheets of identical structure.

Table C-23. Vehicular Emission Factors (CO Shown)

Category	Model Characteristic	Units	Definition/Notes	Source
CO Rates - Gas	CO LDGV	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDGV class for conventional gasoline	U.S. Environmental Protection Agency, MOBILE Motor Vehicle Emission Factor Model, version 6.1/6.2, October 2004.
	CO LDGT12	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDGT1 and LDGT2 classes for conventional gasoline	
	CO LDGT34	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDGT3 and LDGT4 classes for conventional gasoline	
	CO HDGV2b	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 HDGV2b class for conventional gasoline	
CO Rates - RFG Gas	CO LDGV	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDGV class for refined gasoline	U.S. Environmental Protection Agency, MOBILE Motor Vehicle Emission Factor Model, version 6.1/6.2, October 2004.
	CO LDGT12	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDGT1 and LDGT2 classes for refined gasoline	
	CO LDGT34	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDGT3 and LDGT4 classes for refined gasoline	
	CO HDGV2b	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 HDGV2b class for refined gasoline	
CO Rates - Diesel	CO LDDV	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 LDDV class for diesel	U.S. Environmental Protection Agency, MOBILE Motor Vehicle Emission Factor Model, version 6.1/6.2, October 2004.
	CO LDDT12	grams/mile	NO VALUE - NO VEHICLES IN THIS CLASS	
	CO LDDT34	grams/mile	Carbon monoxide emission rate for MOBILE6 class LDDT34 for diesel	
	CO HDDV2b	grams/mile	Carbon monoxide vehicle operation emission rate for MOBILE6 HDDV2b class for diesel	

We used the U.S. Environmental Protection Agency's MOBILE6 mobile source emission factor model to estimate air pollutant emissions per mile traveled by automobiles and different classes of light trucks.[75] We estimated emission factors for automobiles and light trucks manufactured during model years 2005-2030 for each year over the period 2005-2030, in order to capture the effects of age and accumulated mileage on the emission rates. Separate emission factors were estimated for vehicles operating on conventional gasoline, federal reformulated gasoline, and diesel. Emission factors estimated for future model year vehicles and for future calendar year reflect adopted and pending changes in federal emission standards and fuel specifications, including the requirements for low-sulfur gasoline and diesel fuel beginning in 2006.

The pollutants we considered included carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NO_X), sulfur dioxide (SO_2), and fine particulate matter ($PM_{2.5}$, or particulate matter less than 2.5 microns in diameter). Particulate matter includes sulfate particulates, elemental carbon, non-volatile organic carbon compounds, and airborne lead, as well as particulate emissions from brake and tire wear. Because we are concerned with increased emissions from more intensive use of existing vehicles (rather than from a larger vehicle fleet),

[75] U.S. Environmental Protection Agency, MOBILE6.1/6.2 motor vehicle emissions factor model, version 6.2.03, September 23, 2003; see http://www.epa.gov/otaq/mobile.htm.

the emission factors we estimated included only the components associated with vehicle use, and omitted those associated with vehicle storage. Emission components associated with increased vehicle use include exhaust emissions during vehicle start-up and operation, evaporative emissions during vehicle operation, cool-down ("hot soak"), and refueling, and particulate emissions from brake and tire wear.

We estimated emission factors separately for gasoline-powered automobiles (MOBILE6 vehicle class 1), diesel automobiles (class 14), gasoline trucks under 6,000 pounds GVWR (classes 2 and 3), gasoline trucks from 6,000-8,500 pounds GVWR (classes 4 and 5), gasoline trucks from 8,500-10,000 GVWR (class 6), and diesel trucks of each of these same weight classes (classes 15, 28, and 16). We developed composite emission factors for gasoline trucks from 6,000-8,500 pounds GVWR and from 8,500-10,000 GVWR using weighted averages of the two sub-classes of trucks in those weight ranges (classes 2 and 3 and classes 4 and 5 respectively), using as weights MOBILE6's estimates of the fraction of the U.S. vehicle fleet that will be comprised of each of these sub-classes during each year from 2005-30.

We attempted to estimate emission factors that would be representative of those for added vehicle use distributed throughout the U.S. and over times of the day similarly to current aggregate vehicle use. Because carbon monoxide accumulations are a more serious problem during winter months, we estimated CO emission factors for the month of January, assuming typical daily temperatures in more northerly states. Emission factors for other pollutants were estimated for July, assuming a daily temperature range of 65 to 90 degrees. Default values for factors affecting emissions such as the mix of travel by roadway type, travel speeds, variation in trip-making activity over the day, the distribution of trip lengths, altitude, and humidity were assumed. Most of these assumptions tend to produce "worst case" estimates of the contribution to air pollutant concentrations from added rebound-effect driving.

Appendix D. Outputs

Overview

The system produces up to four formatted output files, all as Microsoft Excel workbooks, for each scenario defined in the compliance model parameters file. The system uses folders (*e.g.*, Scenario_0, Scenario_1,...) to organize these files. Table D-1 lists the available output files and their contents. As discussed earlier, the first scenario appearing in the compliance model parameters file is assigned to Scenario 0 and treated as the baseline scenario. Output files for all other scenarios report absolute and relative changes compared to this baseline.[76]

Table D-1. Output File Contents

Input File[77]	**Contents**
Industry_Summary_Sn*.xls	industry-wide results for each regulatory class:[78] sales; average fuel economy, curb weight, area, incurred technology cost, incurred fine, price increase; total technology costs, fines, and increases in sales revenue; technology application and penetration rates
Manufacturer_Summary_Sn*.xls	manufacturer-specific (and industry-wide) results for each regulatory class: sales; average fuel economy, curb weight, area, incurred technology cost, incurred fine, price increase; total technology costs, fines, and increases in sales revenue; technology application and penetration rates
Vehicles_Summary_Sn*.xls	vehicle model-specific results: index, ID number, manufacturer, model name, nameplate, regulatory class, initial and final sales, initial MSRP and price, initial and final fuel economy and curb weight, area, engine ID number and basic characteristics, transmission ID number and type, unit and total technology cost and price increase, application status of each technology
Effects_Summary_Sn*.xls	national-scale effects: travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions, and economic externalities related to highway travel and petroleum consumption

[76] For example, if the baseline scenario involves a flat 22.2 mpg standard for nonpassenger automobiles and Scenario 1 examines a 22.5 mpg standard, Industry_Summary_Sn1.xls might report total technology costs of $2.5b, of which only $0.4b might be attributable to the increase from 22.2 to 22.5 mpg.

[77] Here, the asterisk (*) indicates a number corresponding to a scenario, with 0 indicating the baseline scenario.

[78] As discussed earlier, RC0=unregulated vehicles, RC1=domestic cars, RC2=imported cars, and RC3-RC10=light trucks. Because light truck classes can change from MY to MY, a subtotal for light trucks is also reported. Changes in the composition of regulatory classes can lead to results that may initially be unexpected.

The remainder of this section shows sample output files for a 22.2 mpg nonpassenger automobile standard, with a 20.7 mpg standard in the baseline scenario. Both scenarios address a single model year (2002) and assume a CAFE system with flat standards, an unchanged definition of a nonpassenger automobile, and coverage only up to 8,500 pounds GVWR. Because the output files produced by the system are extensive, the text shows only portions of some files. Also, although the system produces output specific to each represented vehicle model, only the more summarized output files are shown here.

To protect confidential business information and otherwise protected information, the file defining the initial state of the fleet for this example—*demo_market_data.xls*—contains fictitious entries for many fields. Therefore, when used with this file, the system will produce fictitious results. Though useful for diagnostic purposes, such results should be treated as otherwise meaningless, and should not be cited or released.

Industry-Level Summary

Table D-2. Industry-Level Summary (Sample)

Model Years		2002 Total Current Scenario	2002 Total Delta (abs.)	2002 Total Delta (%)
Total Sales	RC 0	28,704	-213	(1%)
	RC 1	4,584,281	-54,411	(1%)
	RC 2	3,615,042	-17,702	(0%)
	RC 3	7,940,496	72,326	1%
	LT Overall	7,940,496	72,326	1%
	Overall	16,168,523	0	(0%)
Average Fuel Economy	RC 0	19.35	0.34	2%
	RC 1	28.32	0.03	0%
	RC 2	29.03	0.02	0%
	RC 3	22.38	1.33	6%
	LT Overall	22.38	1.33	6%
	Overall	25.16	0.83	3%
Average Curb Weight (lb.)	RC 0	4,857	-1	(0%)
	RC 1	3,180	0	0%
	RC 2	3,136	0	0%
	RC 3	4,336	4	0%
	LT Overall	4,336	4	0%
	Overall	3,741	7	0%
Average Area (sq. ft.)	RC 0	117	0	(0%)
	RC 1	94	0	0%
	RC 2	86	0	0%
	RC 3	103	0	0%
	LT Overall	103	0	0%
	Overall	97	0	0%
Average Technology Costs (RPE)	RC 0	$ 164.03	$ 52.70	47%
	RC 1	$ 15.02	$ 3.17	27%
	RC 2	$ 15.98	$ 1.95	14%
	RC 3	$ 300.98	$ 224.90	296%
	LT Overall	$ 300.98	$ 224.90	296%
	Overall	$ 155.94	$ 112.17	256%
Average Fines Incurred (RPE)	RC 0	$ -	$ -	- %
	RC 1	$ -	$ -	- %
	RC 2	$ 4.48	$ (0.03)	(1%)
	RC 3	$ 0.47	$ 0.47	27310%
	LT Overall	$ 0.47	$ 0.47	27310%
	Overall	$ 1.23	$ 0.22	22%
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	RC 0	$ 247.19	$ 148.66	151%
	RC 1	$ 229.27	$ 158.21	223%
	RC 2	$ 50.91	$ 36.30	249%
	RC 3	$ 163.59	$ 120.56	280%
	LT Overall	$ 163.59	$ 120.56	280%
	Overall	$ 157.17	$ 112.38	251%
Total Incurred Technology Costs ($m)	RC 0	$ 4.71	$ 1.49	46%
	RC 1	$ 68.84	$ 13.90	25%
	RC 2	$ 57.79	$ 6.82	13%
	RC 3	$ 2,389.95	$ 1,791.35	299%
	LT Overall	$ 2,389.95	$ 1,791.35	299%
	Overall	$ 2,521.29	$ 1,813.55	256%
Total Fines Owed ($m)	RC 0	$ -	$ -	- %
	RC 1	$ -	$ -	- %
	RC 2	$ 16.21	$ (0.17)	(1%)
	RC 3	$ 3.74	$ 3.72	27562%
	LT Overall	$ 3.74	$ 3.72	27562%
	Overall	$ 19.95	$ 3.55	22%
Total Increase in Sales Revenue ($m)	RC 0	$ 7.10	$ 4.25	149%
	RC 1	$ 1,051.06	$ 721.40	219%
	RC 2	$ 184.05	$ 130.98	247%
	RC 3	$ 1,298.98	$ 960.41	284%
	LT Overall	$ 1,298.98	$ 960.41	284%
	Overall	$ 2,541.18	$ 1,817.04	251%

Manufacturer-Level Summary

Table D-3. Manufacturer-Level Summary (Sample)

Manufacturer		FMC		
		Current Scenario	Delta (abs.)	Delta (%)
Total Sales	RC 0	1,330	2	0%
	RC 1	1,189,623	-16,115	(1%)
	RC 2	275,404	-3,248	(1%)
	RC 3	2,070,865	22,900	1%
	LT Overall	2,070,865	22,900	1%
	Overall	3,537,222	3,540	0%
Average Fuel Economy	RC 0	18.01	0.63	4%
	RC 1	27.50	-0.01	(0%)
	RC 2	27.80	0.01	0%
	RC 3	22.21	1.51	7%
	LT Overall	22.21	1.51	7%
	Overall	24.15	1.03	4%
Average Curb Weight (lb.)	RC 0	5,200	0	0%
	RC 1	3,269	1	0%
	RC 2	3,158	1	0%
	RC 3	4,299	4	0%
	LT Overall	4,299	4	0%
	Overall	3,864	9	0%
Average Area (sq. ft.)	RC 0	119	0	0%
	RC 1	97	0	0%
	RC 2	85	0	0%
	RC 3	105	0	0%
	LT Overall	105	0	0%
	Overall	101	0	0%
Average Technology Costs (RPE)	RC 0	$ 122.50	$ 122.50	- %
	RC 1	$ 43.22	$ 0.03	0%
	RC 2	$ 0.58	$ 0.58	- %
	RC 3	$ 333.42	$ 272.39	446%
	LT Overall	$ 333.42	$ 272.39	446%
	Overall	$ 209.82	$ 159.72	319%
Average Fines Incurred (RPE)	RC 0	$ -	$ -	- %
	RC 1	$ -	$ -	- %
	RC 2	$ -	$ -	- %
	RC 3	$ -	$ -	- %
	LT Overall	$ -	$ -	- %
	Overall	$ -	$ -	- %
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	RC 0	$ 223.57	$ 170.29	320%
	RC 1	$ 243.90	$ 185.73	319%
	RC 2	$ 199.69	$ 152.04	319%
	RC 3	$ 191.58	$ 145.90	319%
	LT Overall	$ 191.58	$ 145.90	319%
	Overall	$ 209.82	$ 159.72	319%
Total Incurred Technology Costs ($m)	RC 0	$ 0.16	$ 0.16	- %
	RC 1	$ 51.41	$ (0.66)	(1%)
	RC 2	$ 0.16	$ 0.16	- %
	RC 3	$ 690.46	$ 565.48	452%
	LT Overall	$ 690.46	$ 565.48	452%
	Overall	$ 742.20	$ 565.15	319%
Total Fines Owed ($m)	RC 0	$ -	$ -	- %
	RC 1	$ -	$ -	- %
	RC 2	$ -	$ -	- %
	RC 3	$ -	$ -	- %
	LT Overall	$ -	$ -	- %
	Overall	$ -	$ -	- %
Total Increase in Sales Revenue ($m)	RC 0	$ 0.30	$ 0.23	320%
	RC 1	$ 290.15	$ 220.01	314%
	RC 2	$ 54.99	$ 41.72	314%
	RC 3	$ 396.74	$ 303.18	324%
	LT Overall	$ 396.74	$ 303.18	324%
	Overall	$ 742.18	$ 565.13	319%

Vehicle-Level Summary

Table D-4. Vehicle-Level Summary Contents

Group	Column	Contents
Index		vehicle model index (internal to code)
ID#		vehicle model ID# (per input file)
Manufacturer		manufacturer abbreviation
Model		model name
Name Plate		name plate name
Reg.Class		regulatory class (0-10)
Total Sales	Initial	initial sales volume (units)
	Final	final sales volume (units)
Initial MSRP ($)		initial MSRP ($)
Initial Price ($)		initial estimated sales price ($)
Fuel Econ.(mpg)	Initial	initial fuel economy
	Final	final fuel economy
Curb Weight (lb.)	Initial	initial curb weight
	Final	final curb weight
Area (sf)		area (overall length x width)
Engine	ID#	engine ID# (per input file)
	Fuel	engine fuel type
	Disp.(lit.)	engine displacement
	Cyl.	number of cylinders
Transmission	ID#	transmission ID#
	Type	transmission type
Unit ($)	Incurred Tech Cost	unit technology cost ($)
	Price Increase	unit price increase ($)
Total ($k)	Incurred Tech Cost	total technology cost ($k)
	Increase in Sales Rev.	total increase in revenue ($k)
Technology Utilization/Applicability '-' tech present in base model, '+' tech applied, '-+' present, but superceded, '++' applied, then superceded, ' ' tech not applied, 'x' not applicable	1LUB	low friction lubricants
	2ROLL	low rolling resistance tires
	3EFR	engine friction reduction
	4OHC	4-valve overhead cam engine
	5VVT	variable valve timing
	6DISP	cylinder deactivation
	7EPS	electric power steering
	8EAI	engine accessory improvement
	95SP	5-speed automatic transmission
	106SP	6-speed automatic transmission
	11ASL	aggressive shift logic
	12CVT	continuously variable transmission
	13AST	automatically shifted clutch transmission
	14AER	aerodynamic drag reductoin
	15VVLT	variable valve lift and timing
	16SUP	supercharging and downsizing
	1742V	42 Volt electrical system
	18ISG	integrated starter/generator
	19CVA	camless valve actuation
	20IVT	intake valve throttling
	21VCR	variable compression ratio
	22ACVT	advanced CVT
	23DSL	conversion to Diesel cycle
	24MS1	materials substitution level 1
	25MS2	materials substitution level 2
	26MS3	materials substitution level 3
	27MSX	weight-increasing materials substitution
	28HEV	conversion to midrange hybrid drive
Employment (U.S. Jobs)		domestic employment

Effects Summary

The summary of effects for each scenario is organized into sections. The second section, shown by example in Table D-6, presents calculated levels of fuel consumed (in thousands of gallons) during the full useful life of all vehicles sold in each model year. Calculated sales volumes, full useful life travel, and average fuel economy levels are also presented to provide a basis for comparison. However, because the system calculates lifetime travel (taking into account the rebound effect) and fuel consumption on a model-by-model basis, these additional aggregate calculations are only generally explanatory, and cannot be used to calculate lifetime fuel consumption.

Table D-6. Effects Summary—Energy Consumption

Energy Consumption				
Lifetime Fuel Consumption (k gal.)	Gas	98,851,030	-2,604,876	(3%)
	Diesel	138,713	-527	(0%)
	Total	**98,989,743**	**-2,605,403**	**(3%)**
Sales	Gas	16,135,518	125	0%
	Diesel	33,005	-125	(0%)
	Total	**16,168,523**	**0**	**(0%)**
Lifetime VMT (k mi.)	Gas	3,069,920,216	12,741,574	0%
	Diesel	5,642,285	-21,421	(0%)
	Total	**3,075,562,501**	**12,720,152**	**0%**
Average Fuel Economy (mpg)	Gas	25.14	0.83	3%
	Diesel	47.85	0.00	(0%)
	Total	**25.16**	**0.83**	**3%**

The third section presents estimates of full fuel cycle carbon dioxide and criteria pollutant emissions, reporting results for the following emissions classes represented in EPA's MOBILE6 emissions model:

Table D-7. MOBILE6 Emissions Classes

Emissions Class	Definition
LDDV	Diesel cars
LDGV	gasoline cars
LDDT1	Diesel trucks with GVW ratings below 6,000 pounds
LDGT1	gasoline trucks with GVW ratings below 6,000 pounds
LDDT2	Diesel trucks with GVW ratings between 6,000 and 8,500 pounds
LDGT2	gasoline trucks with GVW ratings between 6,000 and 8,500 pounds
HDDV2b	Diesel trucks with GVW ratings between 8,500 and 10,000 pounds
HDGV2b	gasoline trucks with GVW ratings between 8,500 and 10,000 pounds

Table D-8 shows sample emissions calculations. As indicated, carbon dioxide emissions are reported in thousand metric tons of carbon-equivalent emissions (one metric ton of carbon dioxide is equivalent to 12/44 of a metric ton of carbon), and all criteria pollutants are reported in short tons (one ton equals 2,000 pounds).

Table D-8. Effects Summary—Emissions

Emissions				
CO2 (k MTCE)	LDDV	414	-2	(0%)
	LDGV	153,286	-1,469	(1%)
	LDDT1	0	0	- %
	LDGT1	108,754	-5,362	(5%)
	LDDT2	0	0	- %
	LDGT2	0	0	- %
	HDDV2b	0	0	- %
	HDGV2b	987	-23	(2%)
	Total	**263,442**	**-6,856**	**(3%)**
CO (tons)	LDDV	3,094	-12	(0%)
	LDGV	19,691,111	-172,203	(1%)
	LDDT1	0	0	- %
	LDGT1	11,902,337	139,099	1%
	LDDT2	0	0	- %
	LDGT2	10,354,158	192,198	2%
	HDDV2b	0	0	- %
	HDGV2b	52,527	-299	(1%)
	Total	**42,003,227**	**158,783**	**0%**
VOC (tons)	LDDV	443	-2	(0%)
	LDGV	487,384	-4,329	(1%)
	LDDT1	0	0	- %
	LDGT1	357,534	745	0%
	LDDT2	0	0	- %
	LDGT2	308,105	5,719	2%
	HDDV2b	0	0	- %
	HDGV2b	2,081	-21	(1%)
	Total	**1,155,547**	**2,112**	**0%**
NOX (tons)	LDDV	504	-2	(0%)
	LDGV	446,426	-4,000	(1%)
	LDDT1	0	0	- %
	LDGT1	354,134	-767	(0%)
	LDDT2	0	0	- %
	LDGT2	337,843	6,271	2%
	HDDV2b	0	0	- %
	HDGV2b	4,865	-41	(1%)
	Total	**1,143,772**	**1,462**	**0%**
PM (tons)	LDDV	100	0	(0%)
	LDGV	23,732	-215	(1%)
	LDDT1	0	0	- %
	LDGT1	15,784	-217	(1%)
	LDDT2	0	0	- %
	LDGT2	7,375	137	2%
	HDDV2b	0	0	- %
	HDGV2b	150	-2	(1%)
	Total	**47,141**	**-298**	**(1%)**
SOX (tons)	LDDV	173	-1	(0%)
	LDGV	70,626	-670	(1%)
	LDDT1	0	0	- %
	LDGT1	51,298	-2,085	(4%)
	LDDT2	0	0	- %
	LDGT2	7,628	142	2%
	HDDV2b	0	0	- %
	HDGV2b	487	-10	(2%)
	Total	**130,212**	**-2,624**	**(2%)**

The fourth and final section of the effects summary presents monetized private and social costs and benefits of each scenario. These effects, discussed in detail in Section III.C.6 of the primary text, include the following:

- Pretax Fuel Expenditures: savings in pretax cost to vehicle users of vehicle fuel
- Fuel Tax Revenues: reduction in total (federal and state) fuel tax revenues
- Travel Value: the value derived from additional driving due to the "rebound efffect"
- Refueling Time Value: savings in the value of vehicle occupants' time during refueling
- Petroleum Market Externalities: reduction in costs of economic externalities resulting from crude petroleum imports
- Congestion Costs: the additional cost of highway congestion from added driving due to the "rebound effect"
- Accident Costs: additional injury and damage costs of highway crashes
- Emissions Damage Costs: the change in damage costs from air pollutant emissions (by species)

In all cases, these costs and benefits are calculated for the fleet of vehicles sold in each model year over their full useful lives, discounted using the rate specified in the benefits model parameters file, and reported in thousands of constant year-2003 dollars.[79] Section III.C.6 of the primary text discusses these types of costs and benefits in greater detail, and Appendix C (Benefits Model Parameters) discusses corresponding input assumptions.

[79] Undiscounted values of these impacts are also reported.

Table D-10. Effects Summary—Private and Social Costs and Benefits

Undiscounted Owner and Societal Costs (k $)			
Total Lifetime Pretax Fuel Expenditures	150,454,238	-4,869,397	(3%)
Fuel Tax Revenues	62,179,342	-2,018,015	(3%)
Travel Value	0	0	- %
Refueling Time Value	0	0	- %
Petroleum Market Externalities	26,378,093	-252,844	(1%)
Congestion Costs	99,527,058	395,397	0%
Noise Costs	1,492,906	5,931	0%
Accident Costs	53,495,793	212,526	0%
CO2	1,436,957	-37,398	(3%)
CO	840,065	3,176	0%
VOC	1,663,410	3,041	0%
NOX	1,646,460	2,105	0%
PM	543,963	-3,441	(1%)
SOX	996,575	-20,084	(2%)
[for future use]			

Discounted Owner and Societal Costs (k $)			
Total Lifetime Pretax Fuel Expenditures	101,395,827	-3,316,706	(3%)
Fuel Tax Revenues	42,980,818	-1,408,383	(3%)
Travel Value	0	0	- %
Refueling Time Value	0	0	- %
Petroleum Market Externalities	15,804,285	-151,490	(1%)
Congestion Costs	60,807,783	253,897	0%
Noise Costs	912,117	3,808	0%
Accident Costs	32,684,183	136,470	0%
CO2	872,541	-22,977	(3%)
CO	429,884	1,653	0%
VOC	796,949	886	0%
NOX	805,488	205	0%
PM	331,737	-2,075	(1%)
SOX	606,525	-12,319	(2%)
[for future use]			

Appendix E. Calibration and Optimization of Reformed CAFE Standards

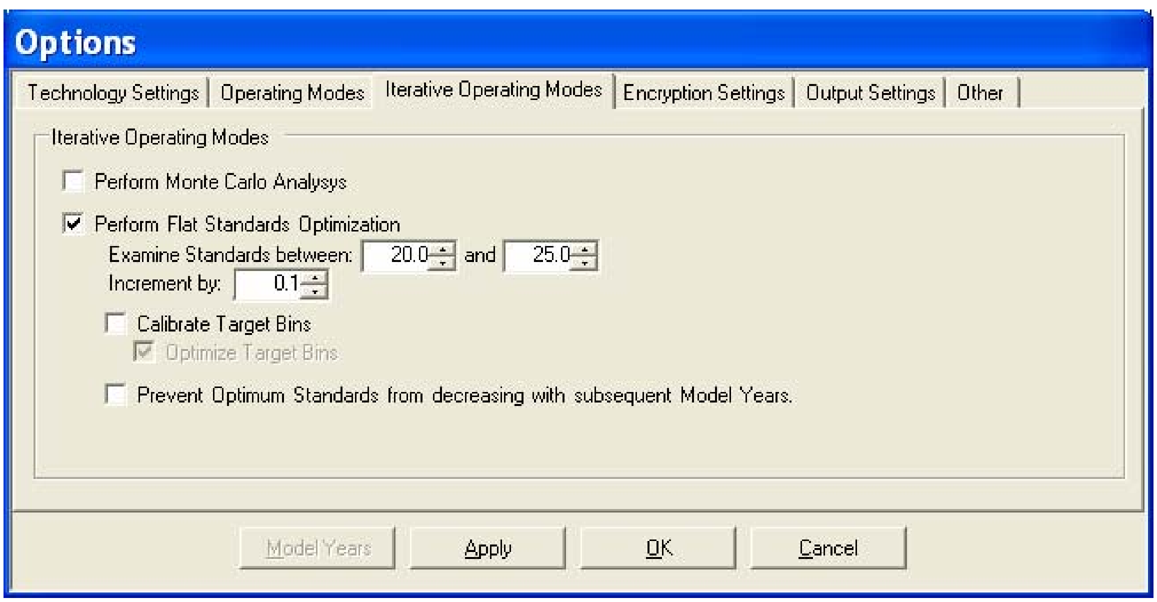
Overview

The calibration and optimization of reformed CAFE standards is a three-stage process. The first step involves determining the optimum CAFE levels for each manufacturer. The second step of the process calibrates the shape of the reformed standard. The last step involves calculating the optimized stringency of the standard, considering all manufacturers represented. Covered model years are optimized sequentially to ensure that technologies are appropriately carried over between model years. During each stage, model data is saved into a temporary location, and is later used as input for the succeeding steps or for generating model outputs.

Step 1. Determining Optimized Manufacturer CAFE Levels

The first stage of automated CAFE optimization involves calculating the optimized CAFE level for each manufacturer. This is achieved by varying the CAFE standard level between the user-specified minimum and maximum values, at the given increment. The results are then saved after each successive trial, including benefits, technology costs, and the CAFE standard. The actual modeling process does not change, except that, during optimizations, the model year loop is invoked repeatedly to satisfy all possible CAFE standards.

Optimization of manufacturer-specific CAFE levels is controlled through settings found on the "Iterative Operating Modes" tab of the "Options" dialog. In the example shown below, CAFE levels from 20 through 25 mpg, at increments of 0.1 mpg, will be tested:



Once all trials have been exhausted, the change in benefits (delta benefits) and the change in technology costs (delta costs) between each successive scenario are calculated. Afterwards, the delta values are used in computing and saving the benefit/cost and marginal benefit/cost ratios for each trial[80]. Finally, the model determines and saves the optimized CAFE value for each manufacturer. The details pertaining to the optimized selection process are explained below, in the Calculating Optimized Value section. Since each model year has to be calculated subsequently for appropriate carry over of technologies, the entire process is repeated for all available years. The optimized CAFE standards from the previous years are used in determining technology carryover.

Step 2. Calibrating Target Function

After the optimized CAFE values for each manufacturer have been determined, the "shape" of the function identifying fuel economy targets under a reformed CAFE system is determined by fitting the selected functional form (currently limited to footprint-based and either stepwise or logistic) to the optimized fleets resulting from step 1. For the stepwise function, the targets are calibrated by assigning all vehicles into six bins, then calculating a sales weighted CAFE value for each individual bin. The bin boundaries are based on the vehicle's area in square feet, and are determined from the scenarios.xls input file.

If a continuous standard is chosen, targets for bins one and six are converted to gallons per mile and used as coefficients *A* and *B* in function number 4 from Table C-8:

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

Here, x is the vehicle footprint and T is the corresponding fuel economy target. Values of C and D are determined through statistical (nonlinear least squares) analysis with A and B fixed at the values determined above.

Step 3. Determining Optimized Industry CAFE

After the continuous function coefficients have been obtained, coefficients *A* and *B* are adjusted up and down at the user specified increment, for a given number of trials above and below the calibrated level[81]. In order to hold the shape of the function constant, coefficients *C* and *D* do not change. The results produced by each trial include benefits, technology costs, and the adjusted coefficients. As with manufacturer-level optimizations, once all trials have completed, the delta benefits and delta costs between successive scenarios are calculated. The delta values are then used in calculating and saving benefit/cost and marginal benefit/cost ratios[82]. Finally, the model computes the optimized *A* and *B* coefficients. Similarly to manufacturer-level

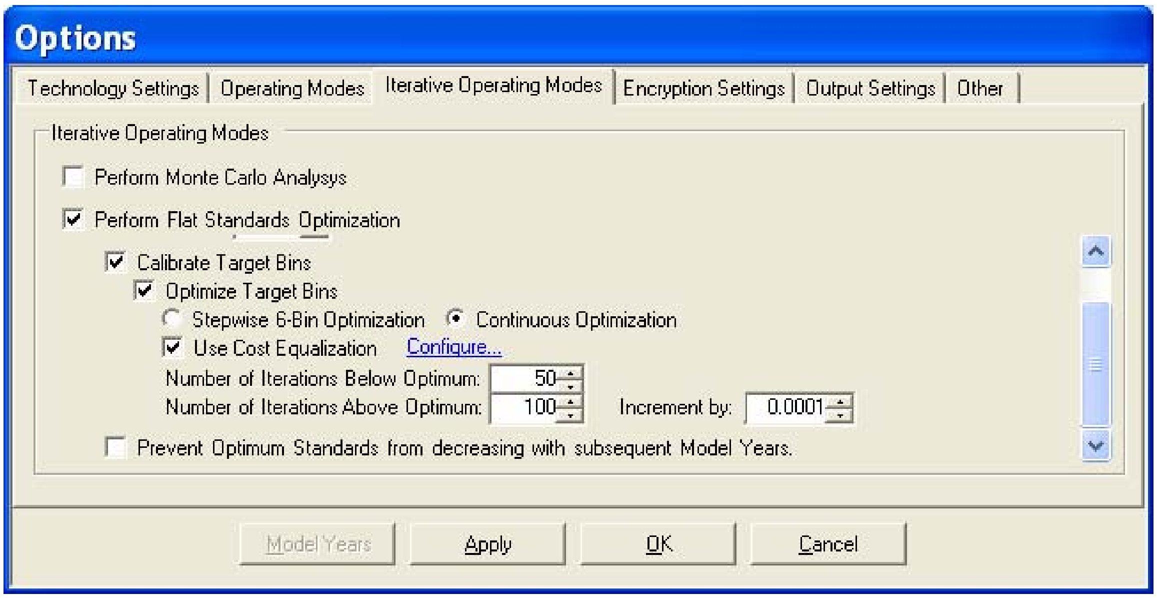
[80] The benefit:cost ratio is calculated by dividing the delta benefits by delta technology costs for the given trial. The marginal benefit:cost ratio, however, is calculated by dividing the change in benefits, between current and previous trials, by the change in costs, between current and previous trials. Optimization is performed using the marginal benefit:cost ratio.

[81] If the user has specified a cost target for the year being examined, the *A* and *B* coefficients will be adjusted until the desired costs are achieved, or until all of the trials have completed, whichever comes first.

[82] The marginal benefit/cost ratio for the industry is calculated by dividing the change in benefits, between following and previous trials, by the change in costs, between following and previous trials.

optimization, each model year is calculated one at a time, with optimum values from the previous years determining technology carryover for the subsequent years. The stringency of the reformed standard (*i.e.*, the values of *A* and *B*) can be either optimized based on marginal benefit:cost ratios or set at levels producing industry-wide technology costs closest to user-specified targets.

Calibration and optimization of reformed standards are also controlled through settings found on the "Iterative Operating Modes" tab of the "Options" dialog. In the example shown below, a continuous function will be calibrated and optimized, testing levels from 0.005 gpm below through 0.01 gpm above the initially calibrated stringency, at increments of 0.0001 gpm:



Calculating Optimized Values

During the manufacturer and industry optimizations, a list of marginal benefit/cost ratios, along with CAFE standards, target bins, or functional coefficients, is saved for each trial. The marginal benefit/cost ratio is then used to calculate where the optimum level lies. The algorithm starts out by examining the first trial, for which the marginal benefit/cost ratio (MBCR) is a real number. If the MBCR is below one, and the model year being examined is not the initial year, the optimum value from the previous year is used. If MBCR is one or above, or the initial year is being examined, the model proceeds to the next step, determining all trials where MBCR crosses the 1:1 boundary. These trials produce a list of all possible optima. The last step of the process is to use the obtained list of cross values to calculate the trial where the optimum is achieved[83].

Initially, the first MBCR cross value is set as the optimum. From there, each cross value is examined, in turn, to decide whether it is a better match. This is done by examining the MBCR

[83] For manufacturer level optimization, determining the trial where the optimum is achieved directly corresponds to determining the optimum CAFE standard. For industry optimization, however, since the optimum has to represent *A* and *B* functional coefficients, determining the optimized trial does not necessarily imply that an optimum will be achieved for *A* and *B* coefficients simultaneously.

values for each trial between the previous MBCR cross value and the current cross value. If there are two consecutive trials with MBCR values below one, then the algorithm returns and the previously set optimum is used. Otherwise, the average of all examined values is calculated, along with the overall average of all MBCR values between the first cross and the current MBCR cross. If, both, the average and overall average values are one or above, the trial corresponding to the current MBCR cross value is set as the optimum, and the algorithm goes on to examine the next cross. If either of the averages is below one, the algorithm simply moves on to the next MBCR cross value. Once all MBCR cross values have been examined, the algorithm returns with the MBCR cross value that was identified as the optimum. The algorithm also handles anomalies, such as outlier values, by capping the maximum and the minimum values for MBCR.

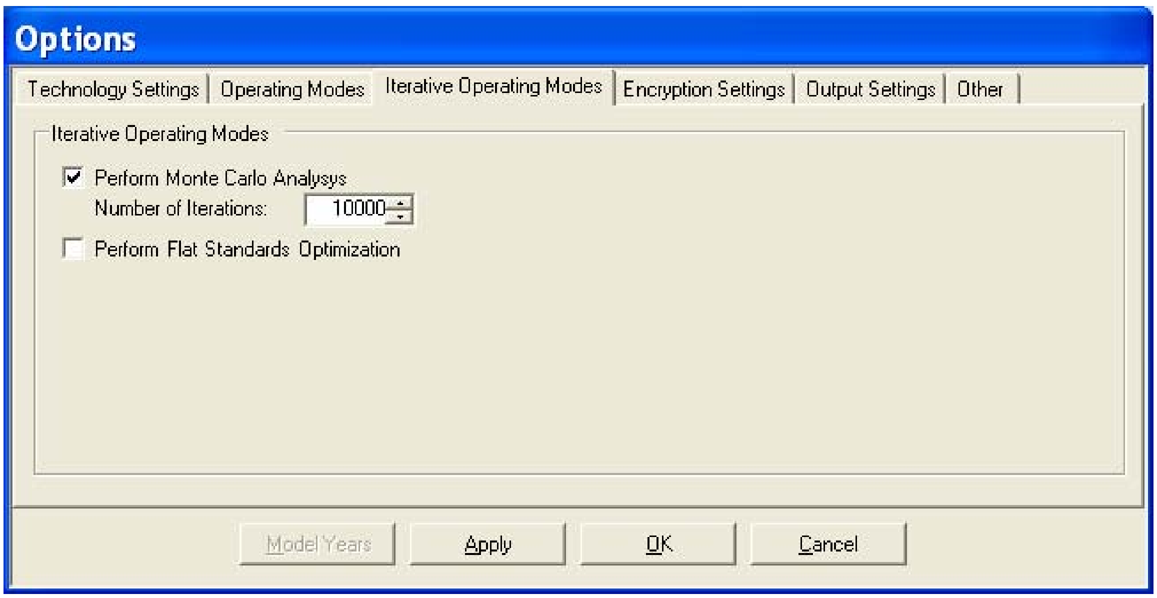
Output files produced during the optimization process show graphs of both benefit:cost and marginal benefit:cost ratios versus stringency, providing a basis for manual determination of optimized stringency levels.

Appendix F. Monte Carlo Analysis

Overview

Sensitivity analysis (*i.e.*, Monte Carlo simulation) may be performed, such that all included scenarios are examined under varying discount rates, technology costs and fuel consumption effects, pretax fuel prices, rebound effect, and fuel-related externalities (monopsony, price shock, and military security costs).

Monte Carlo simulation is selected from the "Iterative Operating Modes" tab of the "Options" dialog. In the following example, 10,000 trials have been selected.



Values for inputs to be varied are specified in a comma-separated-value (CSV) file including the following entries for each trial:

- Trial #
- DiscRate
- Cost(LUB)
- Cost(ROLL)
- Cost(LDB)
- Cost(EFR)
- Cost(FAD)
- Cost(DISP)
- Cost(OHC)
- Cost(VVT)
- Cost(EPS)
- Cost(EAI)
- Cost(5SP)
- Cost(6SP)
- Cost(ASL)
- Cost(CVT)
- Cost(AST)
- Cost(AER)
- Cost(VVLT)
- Cost(SIDI)
- Cost(SUP)
- Cost(42V)
- Cost(ISG)
- Cost(IVT)
- Cost(CVA)
- Cost(VCR)
- Cost(ACVT)
- Cost(DSL)
- Cost(MS1)
- Cost(MS2)
- Cost(MS3)
- Cost(MSX)
- Cost(HEV)
- FC(LUB)
- FC(ROLL)
- FC(LDB)
- FC(EFR)
- FC(FAD)
- FC(DISP)
- FC(OHC)
- FC(VVT)
- FC(EPS)
- FC(EAI)
- FC(5SP)
- FC(6SP)
- FC(ASL)
- FC(CVT)
- FC(AST)
- FC(AER)
- FC(VVLT)
- FC(SIDI)
- FC(SUP)
- FC(42V)
- FC(ISG)
- FC(IVT)
- FC(CVA)
- FC(VCR)
- FC(ACVT)
- FC(DSL)
- FC(MS1)
- FC(MS2)
- FC(MS3)
- FC(MSX)
- FC(HEV)
- Rebound Effect
- Monopsony Cost
- Price Shock Cost
- Military Security Cost
- Pretax Fuel Price Path

Exogenous algorithms are used to apply assumed input variable distributions and thereby develop these input files.

Output files are also in CSV format (one file for each covered scenario), and include the following information for each trial:

- Trial #
- Scen
- DiscRate
- Cost(LUB)
- Cost(ROLL)
- Cost(LDB)
- Cost(EFR)
- Cost(FAD)
- Cost(DISP)
- Cost(OHC)
- Cost(VVT)
- Cost(EPS)
- Cost(EAI)
- Cost(5SP)
- Cost(6SP)
- Cost(ASL)
- Cost(CVT)
- Cost(AST)
- Cost(AER)
- Cost(VVLT)
- Cost(SIDI)
- Cost(SUP)
- Cost(42V)
- Cost(ISG)
- Cost(IVT)
- Cost(CVA)
- Cost(VCR)
- Cost(ACVT)
- Cost(DSL)
- Cost(MS1)
- Cost(MS2)
- Cost(MS3)
- Cost(MSX)
- Cost(HEV)
- FC(LUB)
- FC(ROLL)
- FC(LDB)
- FC(EFR)
- FC(FAD)
- FC(DISP)
- FC(OHC)
- FC(VVT)
- FC(EPS)
- FC(EAI)
- FC(5SP)
- FC(6SP)
- FC(ASL)
- FC(CVT)
- FC(AST)
- FC(AER)
- FC(VVLT)
- FC(SIDI)
- FC(SUP)
- FC(42V)
- FC(ISG)
- FC(IVT)
- FC(CVA)
- FC(VCR)
- FC(ACVT)
- FC(DSL)
- FC(MS1)
- FC(MS2)
- FC(MS3)
- FC(MSX)
- FC(HEV)
- Rebound Effect
- Monopsony Cost
- Price Shock Cost
- Military Security Cost
- Pretax Fuel Price Path
- FuelSavings(2008)
- FuelSavings(2009)
- FuelSavings(2010)
- FuelSavings(2011)
- BCR(2008)

1 BCR(2009)
2 BCR(2010)
3 BCR(2011)
4 SocialBenefits(2008)
5 SocialBenefits(2009)
6 SocialBenefits(2010)
7 SocialBenefits(2011)
8 IndustryTechOutlays(2008)
9 IndustryTechOutlays(2009)
10 IndustryTechOutlays(2010)
11 IndustryTechOutlays(2011)
12 Tech Outlays: BMW(2008)
13 Tech Outlays: SUZ(2008)
14 Tech Outlays: VWA(2008)
15 Tech Outlays: GMC(2008)
16 Tech Outlays: FMC(2008)
17 Tech Outlays: DCC(2008)
18 Tech Outlays: HON(2008)
19 Tech Outlays: HYU(2008)
20 Tech Outlays: NIS(2008)
21 Tech Outlays: TOY(2008)
22 Tech Outlays: FUJ(2008)
23 Tech Outlays: POR(2008)
24 Tech Outlays: ISU(2008)
25 Tech Outlays: BMW(2009)
26 Tech Outlays: SUZ(2009)
27 Tech Outlays: VWA(2009)
28 Tech Outlays: GMC(2009)
29 Tech Outlays: FMC(2009)
30 Tech Outlays: DCC(2009)
31 Tech Outlays: HON(2009)
32 Tech Outlays: HYU(2009)
33 Tech Outlays: NIS(2009)
34 Tech Outlays: TOY(2009)
35 Tech Outlays: FUJ(2009)
36 Tech Outlays: POR(2009)
37 Tech Outlays: ISU(2009)
38 Tech Outlays: BMW(2010)
39 Tech Outlays: SUZ(2010)
40 Tech Outlays: VWA(2010)
41 Tech Outlays: GMC(2010)
42 Tech Outlays: FMC(2010)
43 Tech Outlays: DCC(2010)
44 Tech Outlays: HON(2010)
45 Tech Outlays: HYU(2010)
46 Tech Outlays: NIS(2010)
47 Tech Outlays: TOY(2010)
48 Tech Outlays: FUJ(2010)
49 Tech Outlays: POR(2010)
50 Tech Outlays: ISU(2010)
51 Tech Outlays: BMW(2011)
52 Tech Outlays: SUZ(2011)
53 Tech Outlays: VWA(2011)
54 Tech Outlays: GMC(2011)
55 Tech Outlays: FMC(2011)
56 Tech Outlays: DCC(2011)
57 Tech Outlays: HON(2011)
58 Tech Outlays: HYU(2011)
59 Tech Outlays: NIS(2011)
60 Tech Outlays: TOY(2011)
61 Tech Outlays: FUJ(2011)
62 Tech Outlays: POR(2011)
63 Tech Outlays: ISU(2011)
64 Ave Price Incr: BMW(2008)
65 Ave Price Incr: SUZ(2008)
66 Ave Price Incr: VWA(2008)
67 Ave Price Incr: GMC(2008)
68 Ave Price Incr: FMC(2008)
69 Ave Price Incr: DCC(2008)
70 Ave Price Incr: HON(2008)
71 Ave Price Incr: HYU(2008)
72 Ave Price Incr: NIS(2008)
73 Ave Price Incr: TOY(2008)
74 Ave Price Incr: FUJ(2008)
75 Ave Price Incr: POR(2008)
76 Ave Price Incr: ISU(2008)
77 Ave Price Incr: BMW(2009)
78 Ave Price Incr: SUZ(2009)
79 Ave Price Incr: VWA(2009)
80 Ave Price Incr: GMC(2009)
81 Ave Price Incr: FMC(2009)
82 Ave Price Incr: DCC(2009)
83 Ave Price Incr: HON(2009)
84 Ave Price Incr: HYU(2009)
85 Ave Price Incr: NIS(2009)
86 Ave Price Incr: TOY(2009)
87 Ave Price Incr: FUJ(2009)
88 Ave Price Incr: POR(2009)
89 Ave Price Incr: ISU(2009)
90 Ave Price Incr: BMW(2010)
91 Ave Price Incr: SUZ(2010)
92 Ave Price Incr: VWA(2010)
93 Ave Price Incr: GMC(2010)
94 Ave Price Incr: FMC(2010)
95 Ave Price Incr: DCC(2010)
96 Ave Price Incr: HON(2010)
97 Ave Price Incr: HYU(2010)
98 Ave Price Incr: NIS(2010)
99 Ave Price Incr: TOY(2010)
100 Ave Price Incr: FUJ(2010)
101 Ave Price Incr: POR(2010)
102 Ave Price Incr: ISU(2010)
103 Ave Price Incr: BMW(2011)
104 Ave Price Incr: SUZ(2011)
105 Ave Price Incr: VWA(2011)
106 Ave Price Incr: GMC(2011)
107 Ave Price Incr: FMC(2011)
108 Ave Price Incr: DCC(2011)
109 Ave Price Incr: HON(2011)
110 Ave Price Incr: HYU(2011)
111 Ave Price Incr: NIS(2011)
112 Ave Price Incr: TOY(2011)
113 Ave Price Incr: FUJ(2011)
114 Ave Price Incr: POR(2011)
115 Ave Price Incr: ISU(2011)