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National Highway Traffic Safety Administration

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2012 – 2016 Corporate Average Fuel Economy Compliance and Effects Modeling System Documentation

REPORT DOCUMENTATION PAGE

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The Volpe National Transportation Systems Center (Volpe Center) of the United States Department of Transportation's Research and Innovative Technology Administration has developed a modeling system to assist the National Highway Traffic Safety Administration (NHTSA) in the evaluation of potential new Corporate Average Fuel Economy (CAFE) standards. Based on externally-developed inputs, the modeling system estimates how manufacturers could apply additional fuel-saving technologies in response to new CAFE standards, and estimates how doing so would increase vehicle costs, reduce national fuel consumption and carbon dioxide emissions, and result in other effects and benefits to society. The modeling system can also be used to estimate the stringency at which an attribute-based CAFE standard satisfies various criteria. For example, the system can estimate the stringency that produces a specified average required fuel economy level, or that maximizes net benefits to society.

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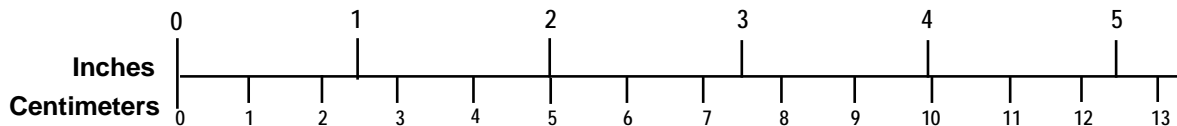| 17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

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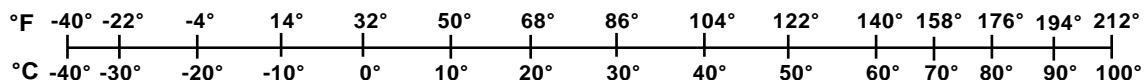Prescribed by ANSI Std. 239-18
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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)

1 foot (ft) = 30 centimeters (cm)

1 yard (yd) = 0.9 meter (m)

1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)

1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)

1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)

1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)

1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)

1 pound (lb) = 0.45 kilogram (kg)

1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)

1 tablespoon (tbsp) = 15 milliliters (ml)

1 fluid ounce (fl oz) = 30 milliliters (ml)

1 cup (c) = 0.24 liter (l)

1 pint (pt) = 0.47 liter (l)

1 quart (qt) = 0.96 liter (l)

1 gallon (gal) = 3.8 liters (l)

1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)

1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)

1 centimeter (cm) = 0.4 inch (in)

1 meter (m) = 3.3 feet (ft)

1 meter (m) = 1.1 yards (yd)

1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)

1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)

1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)

10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)

1 kilogram (kg) = 2.2 pounds (lb)

1 tonne (t) = 1,000 kilograms (kg)

= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)

1 liter (l) = 2.1 pints (pt)

1 liter (l) = 1.06 quarts (qt)

1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)

1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5) y + 32]$ °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0	1	2	3	4	5

Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Abbreviations

a .... vehicle vintage
A_C .... values of attribute (*e.g.*, footprint) of vehicles in regulatory class C
AMT .... automated manual (*i.e.*, clutch) transmission
ASL .... aggressive shift logic
C .... carbon dioxide emissions
C .... regulatory class
c_d .... distribution-related carbon emissions per gallon of fuel consumed
c_f .... carbon content (by weight) of fuel
c_r .... refining-related carbon emissions per gallon of fuel consumed
$CAFE$ .... Corporate Average Fuel Economy
$CAFE_C$ .... CAFE achieved by regulatory class C
CH_4 .... methane
$Cost$ .... technology cost after application of learning effects
$CostD$ .... rate of technology learning
CO .... carbon monoxide
CO_2 .... carbon dioxide
$COST_{eff}$ .... effective cost
$CostUpper$ .... technology cost before application of learning effects
$CREDIT_C$ .... CAFE credits earned in regulatory class C
CVT .... continuously variable transmission
d .... discount rate
DOE .... U.S. Department of Energy
$DOHC$ .... dual overhead cam
DOT .... U.S. Department of Transportation
e_i .... emission rate (per mile) for pollutant i
E_i .... emissions of pollutant i
EIA .... Energy Information Agency, U.S. Department of Energy
EPA .... U.S. Environmental Protection Agency
EPS .... electric power steering
$\Delta FINE$ .... change in civil penalties owed
$\Delta m_{k,MY,t,CAFE}$ .... change in mileage accumulation resulting from rebound effect
$\Delta TECHCOST$ .... change in technology costs
ε_{cpm} .... elasticity of vehicle use with respect to per-mile fuel cost
$FCReduction_{0,1...}$ .... fuel consumption reduction from applied technologies 0, 1, …
FE_C .... fuel economy levels of vehicles in regulatory class C
FE_i .... fuel economy of ith vehicle model
FE'_i .... fuel economy of ith vehicle model, after application of technology
FE_{new} .... fuel economy after application of a technology
FE_{orig} .... fuel economy before application of a technology
$FINE$ .... civil penalties owed
FR .... Final Rule (or Final Rulemaking)
$FUELPRICE_{MY+v}$ .... fuel price in calendar year $MY+v$
$g_{k,MY,t}$ .... fuel used in year t by model k vehicles from model year MY
gap .... gap between laboratory and on-road fuel economy
GDI .... gasoline direct injection

HC ....hydrocarbons
HCCI ....homogenous charge compression ignition
HDDV ....heavy duty diesel vehicle
HDGV ....heavy duty gasoline vehicle
i ....vehicle index
ICP ....intake cam phasing
IMA ....integrated motor assist
ISAD ....integrated starter/alternator/dampener
ISG ....integrated starter/generator
j ....vehicle cohort index
k ....vehicle index
kD ....number of technology learning cost reductions to apply
kWeight ....percentage change in vehicle mass
LDDT ....light duty diesel truck
LDDV ....light duty diesel vehicle
LDGT ....light duty gasoline truck
LDGV ....light duty gasoline vehicle
$lVol_t$ ....intermediate variable for technology learning effect calculations
$m_{k,a}$ ....average mileage accumulated by model k vehicles of vintage a
$mpg_{k,CAFE}$ ....fuel economy of vehicle model k after CAFE standards
$mpg_{k,plan}$ ....fuel economy of vehicle model k before CAFE standards
$M_{k,MY,t}$ ....miles driven in year t by model k vehicles from model year MY
MI_v...............................average annual mileage accumulation at vintage v
MW_C ....molecular weight of carbon
MW_{CO2} ....molecular weight of carbon dioxide
MY ....model year
N_C ....sales volumes of vehicles in regulatory class C
$n_{k,MY}$..............................number of vehicles of model k sold in model year MY
$n_{k,MY,t}$............................number of k vehicles from model year MY in service in year t
$N_{k,MY}$ ....number of vehicles sold in model year MY
NA ....naturally aspirated
NAS ....National Academy of Sciences
NHTSA ....National Highway Traffic Safety Administration
N_2O..............................nitrous oxide
NO_x..................................oxides of nitrogen
NPRM.........................Notice of Proposed Rulemaking
NRC.............................National Research Council
OHV ....overhead valve
$P_{k,MY}$..............................market share of model k sold in model year MY
PM...............................particulate matter
r ....discount rate
r ....fraction of fuel refined domestically
$s_{k,a}$.................................share of vehicles of model k in service at vintage a
PV...............................present value
SI ....spark ignition
STD_C.............................value of CAFE standard as applied to regulatory class C
$SURV_v$..........................average survival rate at vintage v
SO_x ....sulfur oxides
SUV ....sport utility vehicle

t ....calendar year
v.................................vehicle vintage
$VALUE_{fuel}$ ....value of saved fuel
VMT...........................vehicle miles traveled
Volume ....volume after which technology learning effects are realized
VVLT ....variable valve lift and timing
VVT ....variable valve timing

1   Introduction

The Energy Policy and Conservation Act (EPCA), as amended by the Energy Independence and Security Act of 2007 (EISA), requires the National Highway Traffic Safety Administration (NHTSA), an agency within the U.S. Department of Transportation (DOT), to promulgate and enforce Corporate Average Fuel Economy (CAFE) standards. NHTSA has been administering these standards since 1975.

The Volpe National Transportation Systems Center (Volpe Center) provided technical support to the Department in connection with the establishment of the CAFE program in the 1970s, and has continued to provide such support since that time. The Volpe Center is a Federal fee-for-service organization within DOT's Research and Innovative Technology Administration (RITA).

In 2002, the Volpe Center began developing a new modeling system to support NHTSA's analysis of options for future CAFE standards. Objectives included, but were not limited to, the following: the ability to utilize detailed projections of light vehicle fleets to be produced for sale in the United States, the ability to efficiently estimate how manufacturers could apply available technologies in response to CAFE standards, the ability to quickly evaluate various options for future CAFE standards, and the ability to estimate a range of outcomes (in particular, changes in fuel consumption and emissions) resulting from such standards.

Since 2002, the Volpe Center has made many changes to this modeling system. Some changes were made in response to comments submitted to NHTSA in connection with CAFE rulemakings, and in response to a formal peer review of the system. Some changes were made based on observations by NHTSA and Volpe Center technical staff. As NHTSA began evaluating attribute-based CAFE standards (*i.e.*, standards under which CAFE requirements depend on the mix of vehicles produced for U.S. sale), significant changes were made to enable evaluation of such standards. At the same time, the system was expanded to provide the ability to perform uncertainty analysis by randomly varying many inputs. Later, the system was further expanded to provide automated statistical calibration of attribute-based standards, through implementation of Monte Carlo techniques, as well as automated estimation of stringency levels that meet specified characteristics (such as maximizing estimated net benefits to society). In 2007, NHTSA and Volpe Center staff worked with technical staff of the U.S. Environmental Protection Agency (EPA) on major changes to the range of fuel-saving technologies accommodated by the model, as well as the logical pathways for applying such technologies. In 2008, NHTSA and Volpe Center staff collaborated on further revisions, particularly with respect to the representation of available fuel-saving technologies, support for the reexamination of which was provided by Ricardo, Inc.

In support of the 2010 rulemaking, a multi-year technology application feature has been introduced into the modeling system.

2   System Design
2.1   Overall Structure

The basic design of the CAFE Compliance and Effects Modeling System developed by the Volpe Center is as follows: The system first estimates how manufacturers might respond to a given CAFE scenario, and from that the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. A CAFE scenario involves specification of the form, or shape, of the standards (*e.g.*, flat standards, linear or logistic attribute-based standards, scope of passenger and nonpassenger regulatory classes), and stringency of the CAFE standard in each model year to be analyzed.

Manufacturer 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. 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 simulate how a manufacturer might 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 either until the manufacturer achieves compliance, or until the manufacturer exhausts all available technologies, or, if the manufacturer is assumed to be willing to pay civil penalties, until paying fines becomes more cost-effective than increasing vehicle fuel economy. The user may disable the fine paying option for manufacturers expected to be unwilling to pay fines, thus effectively "forcing" the manufacturer to add additional technology even once it might otherwise be preferable to pay fines (considering the cost to add further technology as compared to the estimated value of the resultant saved fuel). 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, fuel types (gasoline, diesel), 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).

Different categorization schemes are relevant to different types of effects. For example, while a fully disaggregated fleet is retained for purposes of compliance simulation, vehicles are grouped by type of fuel for the energy and carbon dioxide calculations, and by U.S. Environmental Protection Agency (EPA) emissions classes for criteria pollutant

calculations. The system may be expanded in the future to represent CAFE-induced market responses (*i.e.*, mix shifting), in which case such calculations would group vehicles by market segment. Therefore, this system uses model-by-model categorization and accounting when calculating most effects, and aggregates results only as required for efficient reporting.

2.2 CAFE Compliance Simulation

2.2.1 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 "scenarios" 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 structure and stringency of the standards applicable to passenger and nonpassenger automobiles. The system is normally used to examine and compare at least two scenarios. 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 future CAFE standards—during the study period, which can cover one or more consecutive model years (MYs). 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.

2.2.1.1 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

2.2.2 Vehicle Technology Application within the CAFE Model

Vehicle technologies are a set of possible improvements available for the vehicle fleet. The vehicle technologies, referred to below simply as 'technologies', are defined in the technology input file for the model (see Appendix A.2). As a part of the definition for each technology there is an associated cost for the technology, an improvement factor (in terms of percent reduction of fuel consumption), the introduction year for the technology, whether it is applicable to a given class of vehicle, grouping (by technology group – engine, transmission, etc.) and phase-in parameters (the amount of fleet penetration allowed in a given year). Also defined in the technology inputs file are cost synergies and improvement synergies.

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 set of technologies accommodated by the model is discussed in NHTSA's Model Years 2012 – 2016 Final Rule (FR) regarding CAFE standards for passenger cars and light trucks produced for sale in the United States in model years 2012 – 2016.[1]

As discussed in the FR, the set of technologies, and the methods for considering their application, builds on a 2002 study by the National Academy of Sciences.[2] That study estimated that the applicability of different technologies would vary based on vehicle type. Although the model now represents a wider range of technologies than the 2002 NAS study, and uses different logical sequences for considering their addition to manufacturers' fleets, the model retains the ability for differentiation based on vehicle type. NAS is currently conducting a study to develop an updated assessment of fuel-saving technologies.

2.2.2.1 Vehicle Technology Class

The CAFE model uses twelve technology classes as shown in Table 1:

Table 1. CAFE Technology Vehicle Classes

Class	Description
Subcompact PC	Subcompact passenger car.
Subcompact Perf.	Subcompact performance oriented passenger car
Compact PC	Compact passenger car
Compact Perf	Compact performance oriented passenger car
Midsize PC	Midsized passenger car
Midsize Perf	Midsized performance oriented passenger car
Large PC	Large passenger car
Large Perf	Large performance oriented passenger car
Small LT	Small sport utility vehicles and pickups

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[1] Federal Register [to be supplied later]. Available on the internet at [to be supplied later].

[2] National Research Council, ''Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,'' National Academy Press, Washington, DC (2002). Available at http://www.nap.edu/openbook.php?isbn=0309076013 (last accessed April 20, 2008). The conference committee report for the Department of Transportation and Related Agencies Appropriations Act for FY 2001 (Pub. L. 106–346) directed NHTSA to fund a study by NAS to evaluate the effectiveness and impacts of CAFE standards (H. Rep. No. 106–940, p. 117–118). In response to the direction from Congress, NAS published this report.

Midsize LT	Midsize sport utility vehicles and pickups
Large LT	Large sport utility vehicles and pickups
Minivan	Minivans

2.2.2.2 Technology Groups:

The CAFE Model organizes technologies into groups. The table below lists the technologies represented by the system, and the grouping we have applied to enable the system to follow a logical incremental path within any given group without being unnecessarily prevented from considering technologies in other groups. This "parallel path" approach is discussed below.

Table 2. Technology Group Assignments

Technology Group	Group Members
Engine Technology Group (EngMod)	Low Friction Lubricants (LUB)
	Engine Friction Reduction (EFR)
	Variable Valve Timing type • VVT Coupled Cam Phasing on SOHC (CCPS) • VVT Couple Cam Phasing on OHV (CCPO) • VVT Intake Cam Phasing (ICP) • VVT Dual Cam Phasing (DCP)
	Cylinder Deactivation • on SOHC (DEACS) • on DOHC (DEACD) • on OHV (DEACO)
	Variable Value Lift & Timing • Discrete Variable Valve Lift [DVVL] on SOHC (DVVLS) • Discrete Variable Valve Lift [DVVL] on DOHC (DVVLD) • Continuously Variable Valve Lift (CVVL) • Discrete Variable Valve Lift [DVVL] on OHV (DVVLO)
	Conversion to DOHC with DCP (CDOHC)
	Stoichiometric Gasoline Direct Injection (SGDI)
	Combustion Restart (CBRST)
	Turbocharging and Downsizing (TRBDS)
	Exhaust Gas Recirculation [EGR] Boost (EGRB)
	Dieselization[3] (DSLC, DSLT)
Electrical Accessory Group (ELEC)	Electric Power Steering (EPS)
	Improved Accessories (IACC)
	12 Volt Micro-Hybrid (MHEV)
	Belt Mounted Starter Generator (BISG)
	Crank Mounted Integrated Starter Generator (CISG)
Transmission Technology Group (TrMod)	6-Speed Manual/Improved Internals (6MAN)
	Improved Auto. Transmission Controls/Externals (IATC)
	Continuously Variable Transmission (CVT)
	6/7/8 Speed Transmission With Improved Internals (NAUTO)
	Dual Clutch or Automated Manual Transmission (DCTAM)
Material Substitution Technology Group (MSM)	Mass Reduction 1.5% (MS1)
	Mass Reduction 3.5 – 8.5% (MS2)
Hybrid Technology Group	Power Split Hybrid (PSHEV)

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[3] Replacing a gasoline engine with a diesel engine.

(HEV)	2-Mode Hybrid (2MHEV)
	Plug-in Hybrid (PHEV)
Dynamic Load Reduction Technology Group (DLR)	Low Rolling Resistance Tires (ROLL)
	Low Drag Brakes (LDB)
	Secondary Axle Disconnect (SAXL)
Aerodynamic Reduction Technology Group (AERO)	Aerodynamic Drag Reduction (AERO)

Input estimates for each of these technologies are specified in the technologies input file, and are specific to each of the CAFE technology vehicle classes, as shown in Table 1. The following table lists the input assumptions specified in this file.

Table 3. Technology Input Assumptions

Input	Definition
FC-Lower	minimum reduction (%) of fuel consumption
FC-Upper	maximum reduction (%) of fuel consumption
Cost-Lower	minimum added cost[4] (in 2007 dollars)
Cost-Upper	maximum added cost (in 2007 dollars)
Learning Type	Indicates whether the learning type is based on time or volume (or neither)
Threshold	For technology costs derived through learning curves, this parameter is used as the threshold volume learning curve cost calculations
Learning Rate	For technology cost derived through learning curves, this parameter is used as the rate of decline in learning curve cost calculations.
Year Available	first model year the technology is available
Applicability	Whether the technology is available for the given vehicle class or not.
Phase-In	Set of percentages showing the phase-in limit at each model year.
Aux.	Used to specify cost basis. If present, identifies whether technology costs are calculated on a per-cylinder, per-engine-bank, or per-pound-removed basis.
Abbr.	abbreviation for technology
TechType	technology group (see technology group (see Table 2))

The technology input assumptions define applicability, cost, fuel consumption reduction factors, and define which technology group of which the technology is a member.

2.2.2.3 Technology Applicability

The technology input assumptions have two means of defining technology applicability. One means is with the *Applicability* field. If the field is set to "TRUE", then the technology is available for the particular class of vehicle, otherwise, the technology is unavailable.

The other applicability control in the input assumptions is the year available field. If the year being modeled by the CAFE Model is prior to the setting in the year available field, then the technology will be unavailable for the particular class of vehicle.

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

Besides those mentioned, there are also other technology applicability factors within the CAFE Model. For example, there are controls for individual vehicles in the market data file that can override the controls here (see Appendix C). There are also dynamic considerations made while the model is running based on vehicle configuration (e.g. cylinder deactivation is not applied to vehicles with manual transmissions), as well as technology combination factors (*e.g.* DVVLD is incompatible with CVVL).

2.2.2.4   Technology Fuel Consumption Reduction Factors

The technology input assumptions—specified in an input file supplied by the user—define the fuel consumption reduction factors *FC_Lower* and *FC_Upper* as a range of low estimate and high estimate. By default, the CAFE Model uses the average of the two. When running the model, the user can direct the model to apply low or high fuel consumption reduction factors.

The reduction in fuel consumption values are on a gallons-per-mile basis and represent a percent reduction in fuel consumption. The formula to find the increase in fuel economy (miles-per-gallon) of a vehicle with fuel consumption reduction factors from one or more technologies, is:

$$FE_{new} = FE_{orig} * \frac{1}{\left(1 - FCReduction_0\right)} * \frac{1}{\left(1 - FCReduction_1\right)} \cdots * \frac{1}{\left(1 - FCReduction_n\right)} \quad (1)$$

where *FE_{orig}* is the original fuel economy for the vehicle and *FCnReduction_{0,1,...n}* are the fuel consumption reduction factors.

2.2.2.5   Technology Cost

The technology input assumptions—specified in an input file supplied by the user—define technology costs *Cost_Lower* and *Cost_Higher* as a range of low estimate and high estimate. By default, the CAFE Model uses the average of the two as shown in equation (2). When running the model, the user can direct the model to apply low or high costs.

Some technology costs have a cost basis associated with them. For instance, for material substitution technologies, the technology input costs must be multiplied by the reduction of vehicle curb weight, in pounds, to get the full cost of applying the technology. Similarly some engine technologies have costs determined on a per cylinder or per bank (configuration) basis. The model uses the 'Aux' column to identify when technologies have an underlying cost basis associated with them, as discussed further in NHTSA's Model Years 2012 – 2016 Final Rule.

Several other technologies involve 'learning'. Learning is a means of capturing the reduction in cost of components and manufacturing process involved with a technology which takes place as the volume of deployment of that technology increases dramatically, or due to other factors, such as negotiated contractual agreements between suppliers and OEMs, which occur over a period of time. The model recognizes these two types of learning, volume-based and-time based. If a technology's cost assumption is based on learning, the *LearningType* field (Table 3) will indicate which type. The formula used for learning cost

based on volume is shown in equation (3), the formula used for learning cost based on time is shown in equation (4).

$$TechCost = \frac{\left(Cost_{higher} + Cost_{lower}\right)}{2} \tag{2}$$

$$kD = 2; cVol = \sum_{i=1}^{i=t} Volume$$
$$lVol_t = \max\left(0, \log_2\left(\min(cVol, 2*kD*Threshold)/Threshold\right)\right) \tag{3}$$
$$TechCost = CostBeforeLearning * (1 - LearningRate)^{lVol_t}$$

$$TechCost = CostBeforeLearning * (1 - LearningRate)^{(year - StartYear)} \tag{4}$$

Where: kD is the a constant representing a maximum of 2 reductions for learning, *Volume* is the volume of deployment of the technology, *Threshold* is the threshold volume and is from the technology input assumptions, *LearningRate* is the rate of decline from the input technology assumptions.

If *LearningType* is left blank or is set to *none*, then the standard cost method is used, otherwise the indicated learning method (*VOLUME* or *TIME*) is used. Reduction due to learning do not take place in the CAFE Model until the technology is available and applied.

Other fields in the input assumptions are the *TechType* and *Abbr*. *Abbr* contains abbreviations of the technology. The *TechType* field specifies the technology group. Technology groups are shown in Table 2 on page 6. Technology groups are discussed below.

The CAFE Model 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.

Further discussion of the technology input assumptions can be found in Appendix A.2.

2.2.2.6 Technology Synergies

Technology synergies exist when the combination of two technologies yields a fuel consumption reduction or cost which differs from what would be derived directly from equation (1) for fuel consumption reduction and equations (2), (3) above (4) for cost. The synergy can be positive (e.g. increased reduction of fuel consumption or increase in cost) or negative (decreased reduction of fuel consumption or decrease in cost).

Synergy relationships between technologies are captured in the two synergies table in the technology input file. The system reads the information from the table and, for each

technology, stores the synergy factors between that technology and all other technologies. For cases where there is no synergy relationship, there will be no listing in the table, and the synergy factor will be zero (0.0). In cases where there are synergies, that applicable factor is added to the fuel consumption reduction or to the cost value.

In the case of fuel consumption reduction synergies, negative synergies lessen the fuel consumption reductions of a technology, the system assumes technologies will not combine to degrade fuel economy (*i.e.,* to produce negative reductions in fuel consumption). For synergies involving technology costs, the final result is allowed to become negative.

The layout of the synergy table in the technology input file is discussed in Appendix A.2.

2.2.2.7   Technology Groups:

Technology groups, as shown in Table 2 on page 6, organizes the technologies into functional groups and allows the model to seek the next "best" technology application in any of the groups.[5] There are seven groups: engine technologies; transmission technologies; electrical accessory technologies; dynamic load reduction technologies; aerodynamic load reduction technologies; material substitution technologies; and hybrid electric vehicle technologies.

2.2.2.8   Backfill of Technologies

In some cases, technologies will be bypassed because they are not cost-effective. If the model applies a technology that resides later in the sequence, the model will 'backfill' any bypassed technologies. This backfill will not occur if the technology is not applicable to the vehicle. In the case where the backfill would backtrack through branches in the sequence, the model would first resolve any limitations and applicability issues. If the branch still exists, it would examine which is the more cost-effective branch to use.

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 market data input file, and increases the cost and fuel economy of affected vehicles in the current model year.[6] 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.

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[5] Within the context of the compliance simulation, "best" is defined from the manufacturers' perspective. The system assumes that the manufacturer will seek to progress through the technology decision trees in a manner that minimizes effective costs, which include (a) vehicle price increases associated with added technologies, (b) reductions in civil penalties owed for noncompliance with CAFE standards, and (c) the value vehicle purchasers are estimated to place on fuel economy.

[6] 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, 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.[7] If any such overrides have been specified, the algorithm reevaluates applicability as shown in Figure 7.

2.2.2.9   Technology Sequencing and Branching

The sequence of applying technology works in the following way: Within each group, the technology sequence of application proceeds as shown in the technology input file. There are some points where the sequence path can branch onto a different course, as discussed below. The groups are independent of each other, although there are some interactions, as described below.

2.2.2.9.1   Sequencing and branching within a technology group

Within each technology group, the choice of technologies that can be applied may vary from vehicle to vehicle based on the baseline configuration of the vehicle or on the previous application of technologies. Both the engine and transmission technology groups have optional paths. The choice of which path depends upon a variety of factors which include the vehicle class, the vehicle configuration, technology override settings for that vehicle, previous applications of technology, technology availability (year available) and phase-in restrictions. When left with a choice of two or more technologies, cost-effectiveness is used to choose the technology to apply.

2.2.2.9.2   Bypassing a Technology

In cases where a technology is already installed in the baseline vehicle configuration or is unavailable for other reasons (*e.g.*, it is not compatible with this vehicle class), then that technology is simply bypassed in the technology path. For example, if engine friction reduction has previously been installed, then the next available engine technology after low -cost lubricants on a vehicle with overhead valves (OHV) is cylinder deactivation.

Branching within a technology group sequence occurs for the following reasons: 1) A normal branch where there are two or more different (and mutually incompatible) technology choices – the model can choose one or another path; 2) Limitations of technology choice based on vehicle configuration; 3) A combination of both.

Examples of normal branches are DVVLD and CVVL in the engine technology group and CVT or NAUTO in the transmission technology group.

An example of the limitations would be within the engine technology group, as shown in Figure 2, below, where there is a separate path for engines with overhead valves (OHV)

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[7] These overrides, described in Appendix C.2 on page 59, provide a means of accounting for engineering and other issues not otherwise represented by input data or the overall system.

engines, single overhead cam engines (SOHC) and for engines with dual overhead cams (DOHC).

2.2.2.9.3 Engine Technology Sequencing and Branching

Within the engine technology sequence, shown in Figure 2, there are three major sequence paths: single overhead cam (SOHC); dual overhead cam (DOHC); and overhead valve (OHV). The choice of path for a vehicle model is based on the base engine attributes. There are further branches within the DOHC branch and within the OHV path. The choice of which branch to take is based on availability for the specific vehicle as well as the vehicle class; phase-in constraints; and, finally, cost-effectiveness.

Further down within the engine technology sequence is another branch which culminates in dieselization. The choice of which branch is, again, based on availability for the specific vehicle as well as the vehicle class; phase-in constraints; and, finally, cost-effectiveness.

2.2.2.9.4 Transmission Technology Sequencing and Branching

Within the transmission technology sequence, for vehicles with a base 4- or 5-speed automatic transmission, there are branch options based in part on vehicle attributes (unibody versus ladder frame). Further criteria used to decide which branch to take are availability for the specific vehicle as well as the vehicle class; phase-in constraints; and, finally, cost-effectiveness. Manual transmissions remain in their own path.

The sequence for transmission technologies is shown in Figure 3.

The transmission technologies and those on the electrical accessory path are considered enabler technologies that must be installed on a vehicle prior to the application of the strong hybrid technologies. Therefore, the model fully (*i.e.*, as subject to all other constraints) applies technologies in both of these paths before applying power-split, two-mode, or plug-in hybrid technologies

2.2.2.9.5 Electrical Accessory Technology Sequence

The electrical accessory technology sequence has no branches, as shown in Figure 5. This group is an enabler for strong hybrid technologies.

2.2.2.9.6 Strong Hybrid Technology Options

As discussed above, the transmission technology and electrical accessory technology sequences are enablers for strong hybrid technologies. Once currently-available opportunities to add technologies on these two sequences have been exhausted, the system evaluates opportunities to apply strong hybrids. As shown in Figure 6 which also illustrates the enabling nature of the transmission and electrical accessory sequences, the system selects among power split, two-mode, and plug-in hybrids.
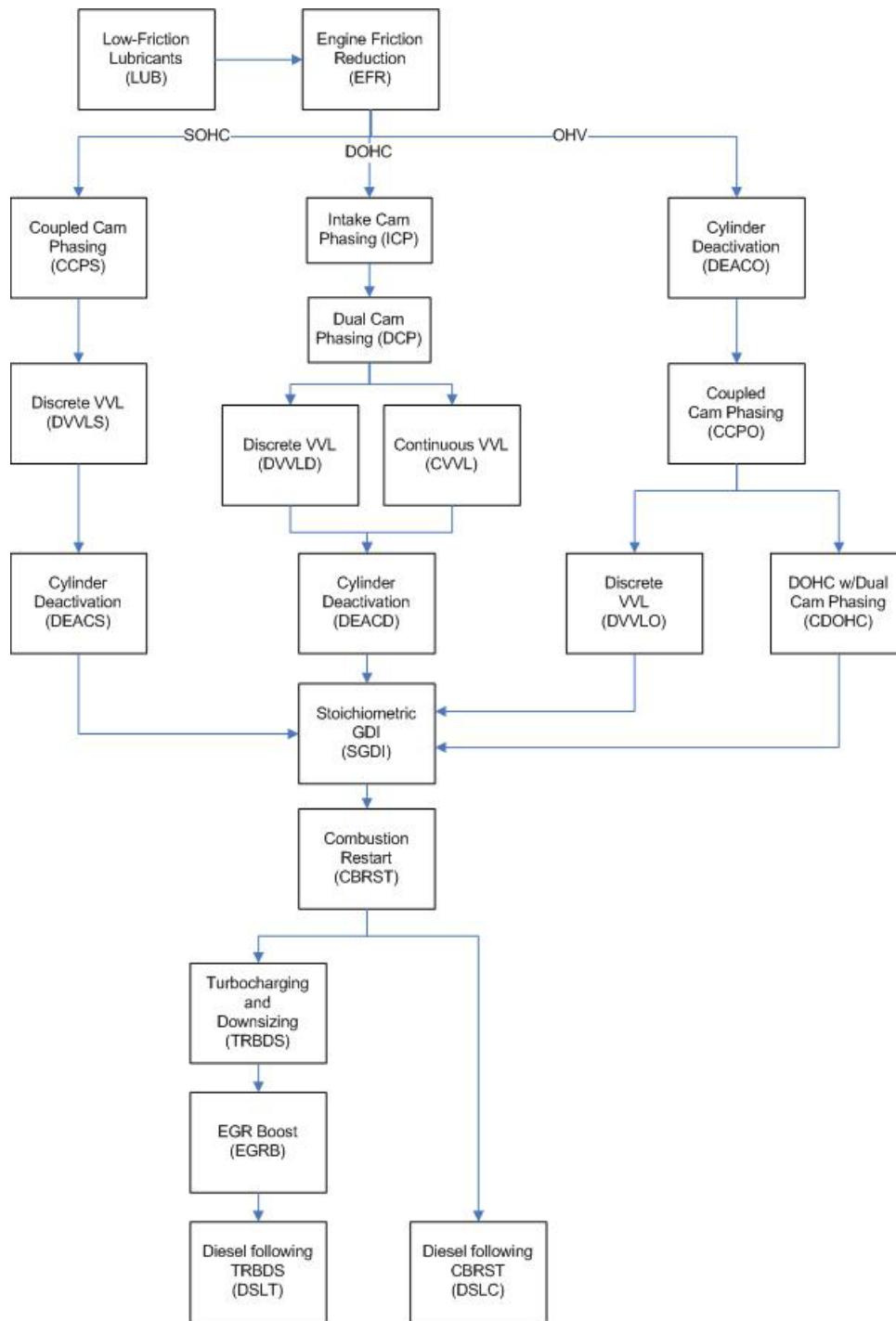
Figure 2. Engine Technology Group Technology Sequence

13
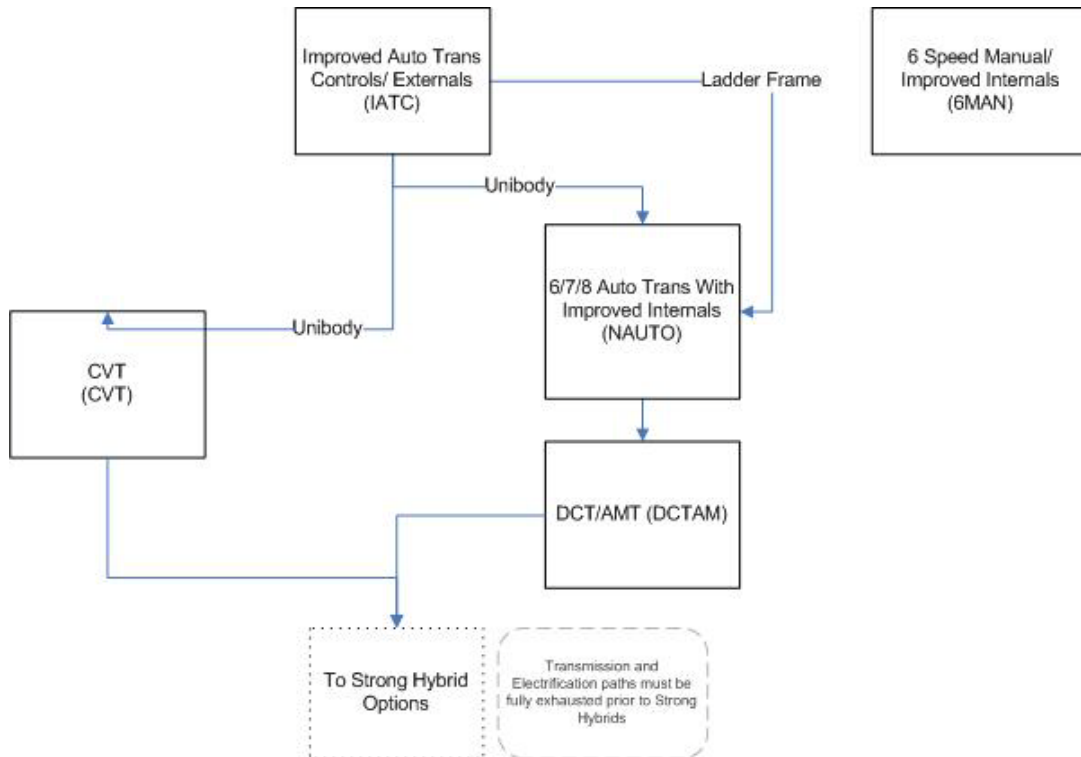
Figure 3. Transmission Technology Group Technology Sequence
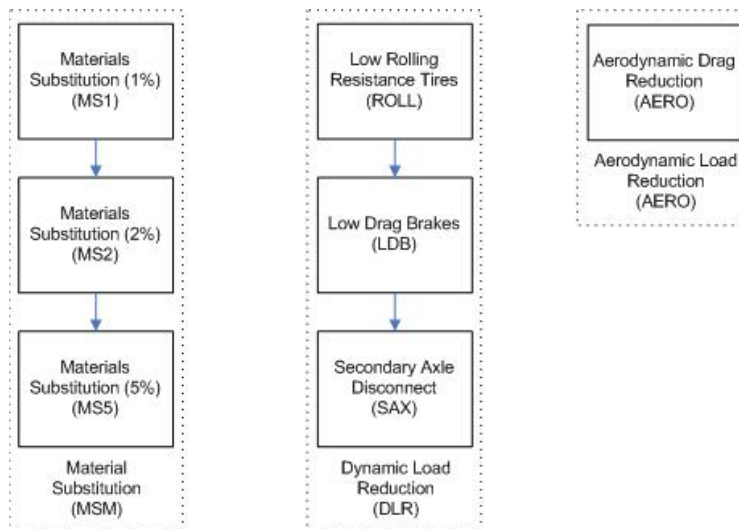
Figure 4. Other Vehicle Technology Sequencing.
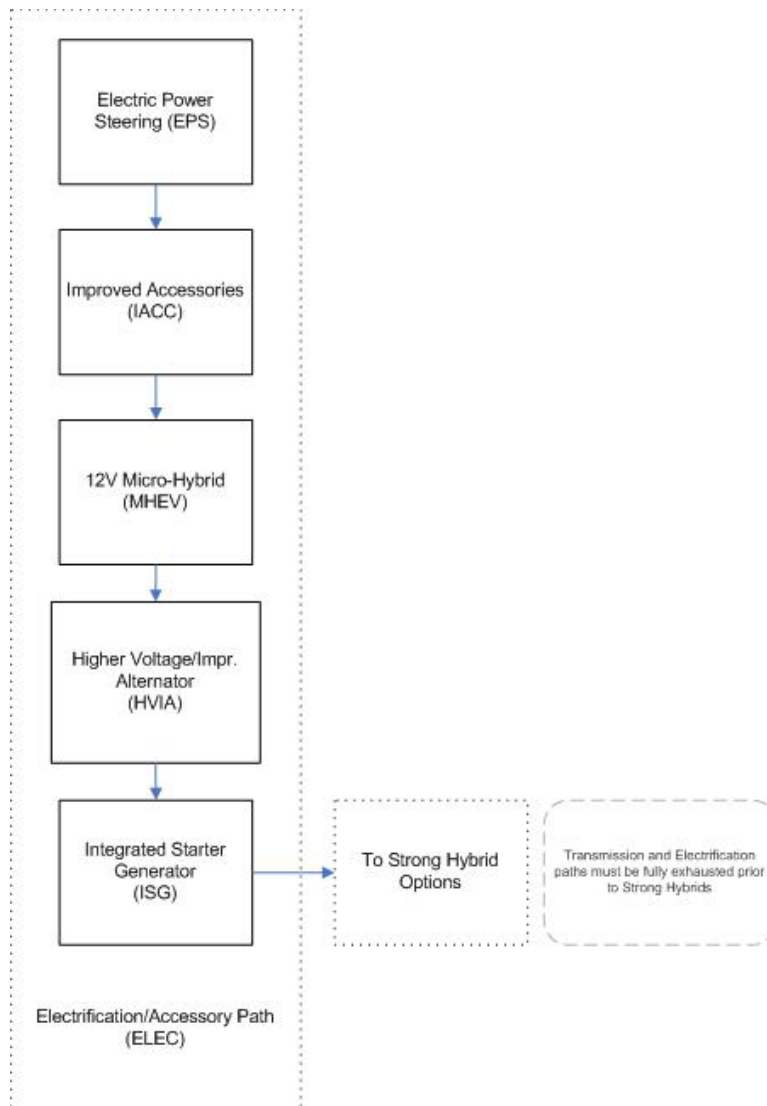
Figure 5. Electrical Accessory Technology Group Sequencing
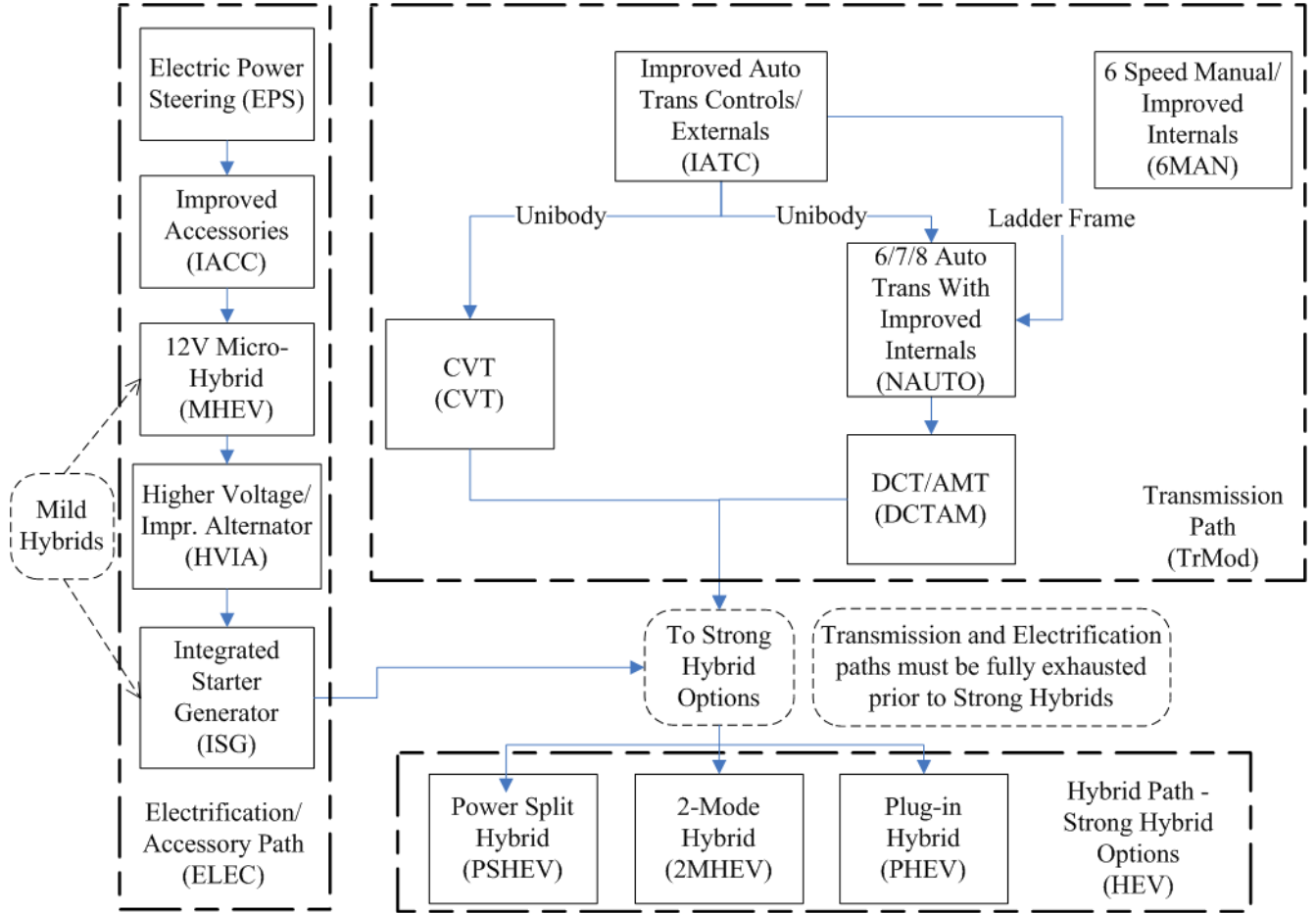
Figure 6. Strong Hybrid Electric Vehicle Options
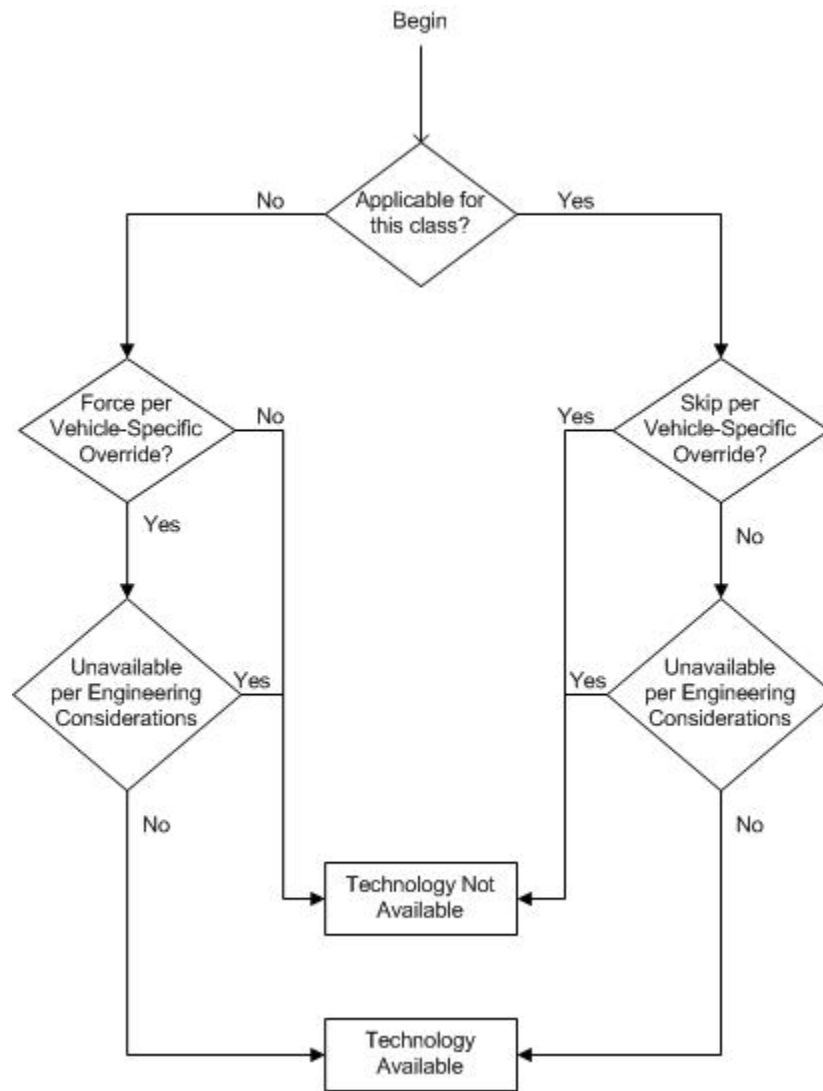
Figure 7. Technology Applicability Determination

2.2.3   Compliance Simulation Loop

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

Table 4. Engineering Conditions for Technology Applicability

Technology	Constraint
All technologies	Do not apply if already present on the vehicle.
Low-Friction Lubricants	Do not apply if engine oil is better than 5W30
Variable Valve Timing Family	Do not apply to diesel or rotary engines.
Variable Valve Lift and Timing Family	Do not apply to diesel or rotary engines. Do not apply to vehicles with VVLT technology already in place. Once a VVLT (continuous or discrete) are applied, the other VVLT cannot be applied.
Cylinder Deactivation	Do not apply to engines with inline configuration, and/or fewer than 6 cylinders. Do not apply to diesel or rotary engines.
Turbocharging and downsizing	Do not apply to diesel or rotary engines.
Stoichiometric GDI	Do not apply to diesel or rotary engines.
Continuously Variable Transmission	Apply only to FWD unibody vehicles.

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" (as described above) technology available on each of the parallel technology paths mentioned above, and applying the best of these.

Figure 8 gives an overview of the process. If, considering all regulatory classes, the manufacturer owes no CAFE fines, then the algorithm applies no technologies beyond any carried over from the previous model year, because the manufacturer is already in compliance with the standard. If the manufacturer does owe CAFE fines, then 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), then 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, then 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, then the algorithm stops applying technology to this manufacturer's products. After this process is repeated for each manufacturer. It is then repeated again for each modeling year. Once all modeling years have been processed, the compliance simulation algorithm concludes.
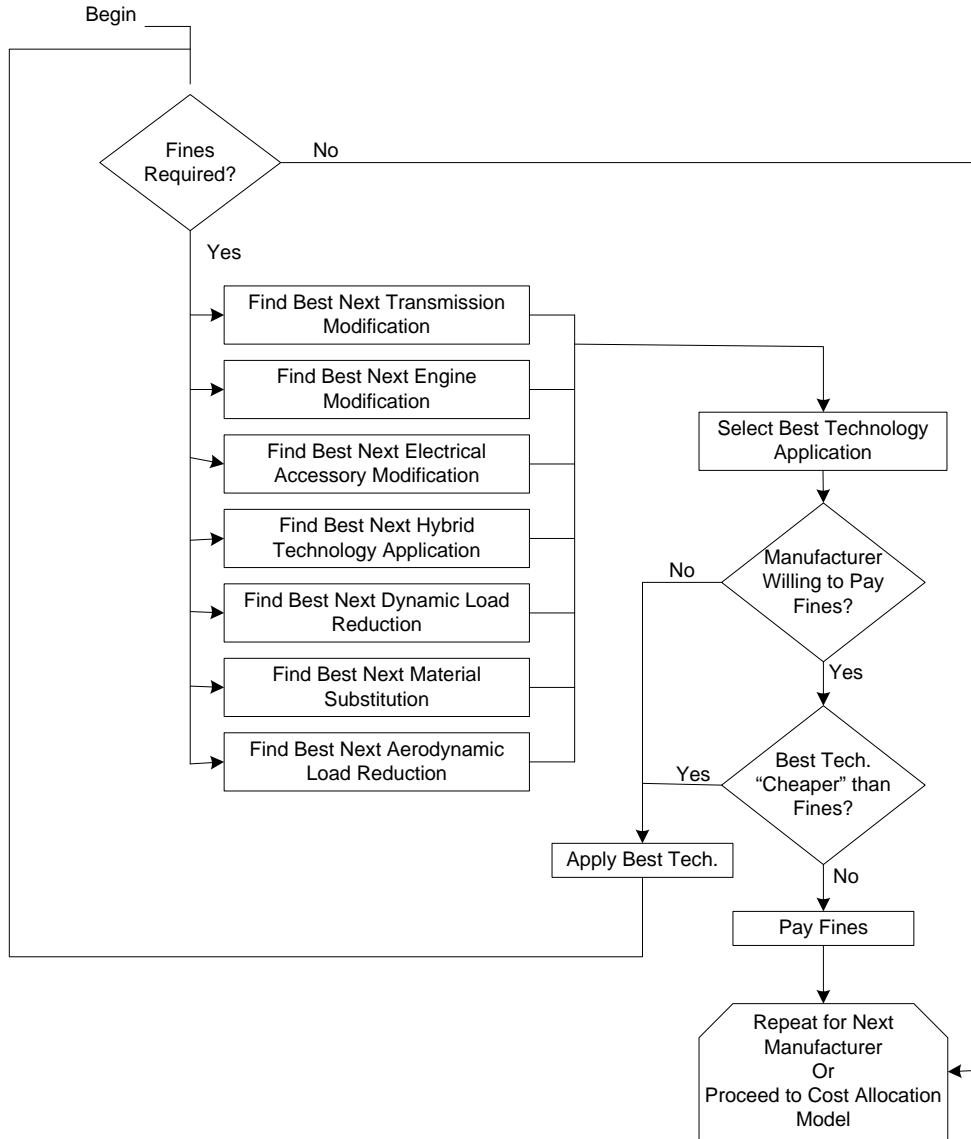
Figure 8. Compliance Simulation Algorithm

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 to 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.[8] The effective cost is used for

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[8] 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.

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, The calculation can span multiple modeling years. If the candidate technology was enabled for application in a previous year and not used, then it can remain as a candidate to be applied and then carried forward to the current model year. The impact of the technology application in each of these years is summed to obtain the effective cost.

$$COST_{eff} = \sum_{i=BaseMY}^{i=PresentMY} \frac{\Delta TECHCOST_i + \Delta FINE_i - \left(VALUE_{FUEL} \right)_i}{\left(N_j \right)_i} \tag{5}$$

where *PresentMY* is the current modeling year, *BaseMY* is the first year of the potential application of the technology (can be less than or equal to *PresentMY*), *ΔTECHCOST* is simply the product of the unit cost of the technology and the total sales (N_j) of the affected cohort of vehicles (j) for all years involved in the candidate technology application. 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:[9]

$$VALUE_{FUEL} = \sum_{i \in j} \left[N_i \sum_{v=0}^{v=PB} \frac{SURV_v MI_v FUELPRICE_{MY+v}}{(1-gap)(1+r)^{v+0.5}} \left(\frac{1}{FE_i} - \frac{1}{FE_i'} \right) \right] \tag{6}$$

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 scenarios file.

In equation (5), *FINE* is the change in total CAFE fines (*i.e.*, accounting for all regulatory classes in the current CAFE scenario and model year). Typically, *FINE* is negative because applying a technology would increase CAFE.[10] *FINE* is calculated by evaluating the following before and after the pending technology application, and taking the difference between the results:

$$FINE = -k_F \sum_C MIN \left(CREDIT_C, 0 \right) \tag{7}$$

Here, k_F is in dollars per mpg (*e.g.*, \$55/mpg) and specified in the scenarios file.

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[9] 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.

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

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 attribute-based CAFE standards, this is expressed as follows:

$$CREDIT_C = N_C \left[\text{STD}_C \left(\mathbf{N}_C, \mathbf{A}_C \right) - \text{CAFE}_C \left(\mathbf{N}_C, \mathbf{FE}_C \right) \right] \qquad \textbf{(8)}$$

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 $\text{STD}_C(\mathbf{N}_C, \mathbf{A}_C)$ is a function defining the standard applicable to regulatory class C.

Figure 9 gives an overview of the logic the algorithm follows in order to identify the best next technology application for each technology group.

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 8, the algorithm repeats this process for each technology group, and then selects the technology application yielding the lowest effective cost. As discussed above, the algorithm operates subject to expectations of the willingness of each manufacturer to pay fines. $COST_{eff}$ is determined, as above, by equations (5), (6), (7) and (8), irrespective of the manufacturer's willingness to pay fines.

At the end of each year in the model year loop, the vehicle/technologies combinations that can be candidates for application in multi-year processing are identified.

Begin

Evaluate next tech. on path

Has ramp-up limit for pending tech. been reached?
Yes

No

Can pending tech. still be applied to some vehicles?
No   Yes

Evaluate potential applications of pending technology

Calculate $\mathbf{FE}_i$, A_i ($i \in j$) if pending tech. applied to vehicle group j

Calculate technology cost (total RPE increase)

Calculate value of saved fuel

Calculate class-specific standards, CAFEs, and credits

Calculate total CAFE fine

Calculate effective cost

Can pending tech. be applied to any other vehicle groups?
Yes   No

Choose best next application (yields lowest effective cost)

Evaluate other tech. paths

Figure 9. Determination of "Best Next" Technology Application

2.3 Calculation of Effects

This section describes how the CAFE modeling system estimates the effects of tightening or reforming CAFE standards on energy use, as well as on emissions of greenhouse gases and other air pollutants. These effects are caused by improvements in the fuel economy of vehicle models as manufacturers respond to changes in the CAFE standards. This section also describes how these energy use and environmental impacts are translated into estimates of economic benefits or costs, and identifies which of these economic impacts are borne privately by vehicle owners and by society as a whole.

The effects on energy use and 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. A vehicle model's life span extends from the initial model year when it is produced and sold, through the year when vehicles produced during that model year have reached the maximum age used in the CAFE model.[11] 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 its value 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 a CAFE class (domestic automobiles, import automobiles, and light trucks) produced during each model year affected by a proposed 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 produced.

2.3.1   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:

$$n_{k,MY} = N_{MY} P_{k,MY} \qquad (9)$$

Where N_{MY} indicates the forecast of total new light-duty vehicle sales during that model year, and $P_{k,MY}$ is the forecast market share of each vehicle model produced during that year.

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

$$n_{k,MY,t} = n_{k,MY} s_{k,a} \qquad (10)$$

where $s_{k,a}$ denotes the proportion of vehicles of model k expected to remain in use at the age (a) that vehicles produced during model year MY will have reached during year t, which is defined as

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

$$a = t - MY. \text{[12]}$$

The model utilizes different schedules of expected survival rates by vehicle age for six separate classes of light-duty vehicles, as reported in Appendix C. The CAFE model assumes that these survival rates will not vary for future model years.

2.3.2 Vehicle Use and Total Mileage

The total number of miles driven by vehicles of a specific model and vintage (model year) during each year they remain in the fleet is calculated by multiplying age-specific estimates (model inputs) of annual miles driven per vehicle by the number of vehicles of that model year remaining in service at their age during that future year. 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:

$$M_{k,MY,t} = n_{k,MY,t} m_{k,a} \tag{11}$$

where $m_{k,,a}$ is the average number of miles that a surviving vehicle of model k is driven when it has reached age a, defined above. The CAFE model uses separate estimates of average annual utilization at different ages for different classes of light-duty vehicles. As with survival rates, we assume that annual usage of vehicles of different types at each age during their expected lifetimes will remain unchanged for future model years.

2.3.2.1 Accounting for the "Rebound Effect"

By reducing the amount of fuel it consumes per mile, improving a vehicle's fuel economy reduces its fuel cost per mile driven. In response to the reduced per-mile cost of driving a more fuel-efficient vehicle, some buyers will increase the amount of driving they do, although the precise magnitude of this response is uncertain. Thus, imposing stricter fuel economy standards can increase the annual number of miles driven by vehicle models whose fuel economy manufacturers elect to improve in their efforts to comply with those standards.[13] This increase in the use of vehicles with increased fuel economy is referred to as the "rebound effect" in vehicle use.

The rebound effect results in a corresponding increase in the *total* number of miles driven by vehicles produced during each model year affected by the stricter standards for every 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

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[12] We define a vehicle's age to be 0 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 2015. 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.

[13] 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.

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

$$\frac{\Delta m_{k,MY,t,CAFE}}{m_{k,MY,t}} = \varepsilon_{cpm} \left[\frac{\dfrac{f_t}{mpg_{k,CAFE}} - \dfrac{f_t}{mpg_{k,plan}}}{\dfrac{f_t}{mpg_{k,plan}}} \right] \tag{12}$$

where ε_{cpm} (a model input) is the elasticity of vehicle use with respect to the cost of fuel per mile driven (a measure closely related to the magnitude 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 equation (12) represents the proportional reduction in fuel cost per mile driven resulting from the improvement in fuel economy.[14]

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

$$\Delta m_{k,MY,t,CAFE} = \varepsilon_{cpm} \left(\frac{mpg_{k,MY,plan}}{mpg_{k,MY,CAFE}} - 1 \right) m_{k,MY,t} \tag{13}$$

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

$$\Delta M_{k,MY,t,CAFE} = n_{k,MY,t} \Delta m_{k,MY,t,CAFE} \tag{14}$$

where $n_{k,MY,t}$ is given by equation (10).

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 stricter CAFE standard. 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 will result in an increase in their use over each year of their expected lifetime. In particular, where a manufacturer's product plan specifies fuel economy levels that do not meet the CAFE standard in effect during the previous model year, the increase in their fuel economy necessary to ensure compliance with the baseline standard will produce a slight increase in their lifetime use through the rebound effect.

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[14] For Equation (11) 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:

$$\Delta M_{k,a,t,CAFE1} - \Delta M_{k,a,t,CAFE0} = n_{k,a,t}\left(\Delta m_{k,a,t,CAFE1} - \Delta m_{k,a,t,CAFE0}\right) \quad (15)$$

2.3.3 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 affected 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.

The computation is also affected 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:

$$g_{k,MY,t} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY}\left(1 - gap\right)} \quad (16)$$

where gap (a model input) 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.[15]

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.*, $M_{k,MY,t} = 0$), and

$$g_{k,MY,t,plan} = \frac{M_{k,MY,t}}{mpg_{k,MY,plan}\left(1 - gap\right)} \quad (17)$$

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 equation (17) is:

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

$$g_{k,MY,t,CAFE} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1 - gap)} \tag{18}$$

or, equivalently:

$$g_{k,MY,t,CAFE} = \frac{M_{k,MY,t}}{mpg_{k,MY,CAFE}(1 - gap)} + \frac{\Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1 - gap)} \tag{19}$$

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 (18) or (19) over all vehicle models produced during the model years to which the alternative standard would apply:

$$G_{t,CAFE1} = \sum_{MY} \sum_{k} \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) \tag{20}$$

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 used is that this baseline standard would be an extension of the CAFE standard that applied to vehicles produced during the preceding model year.

The fuel savings from imposing a stricter CAFE standard on vehicles produced during a single model year *MY* over their expected lifetime are given by:

$$G_{MY,CAFE1} = \sum_{t} \sum_{k} \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) \tag{21}$$

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:

$$PV\left(G_{MY,CAFE1} \right) = \sum_{t} \sum_{k} \left(\frac{g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}}{(1+d)^{t-MY}} \right) \tag{22}$$

where d is the annual discount rate.

2.3.4 Greenhouse Gas Emissions

Environmental impacts from petroleum use stem primarily from combustion of petroleum products such as gasoline, and to a lesser extent from the use of fossil energy during petroleum refining and in the transportation, storage, and distribution of refined products. These impacts include emissions of greenhouse gases and "criteria" air pollutants currently regulated under the Clean Air Act. Increasing 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 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 emissions of these pollutants. Thus on balance, raising CAFE standards can either reduce or increase emissions of criteria pollutants, depending on the magnitude of the rebound effect, vehicles' emission rates per mile driven, and emissions produced during fuel refining and distribution.

Fuel savings from stricter light truck CAFE standards will result in lower emissions of carbon dioxide, the primary greenhouse gas emitted during the refining, distribution, and combustion of transportation fuels.[16] Lower fuel consumption reduces carbon dioxide emissions directly, because the largest source of these emissions in transportation is fuel use in internal combustion engines. The CAFE model calculates reductions in carbon dioxide emissions from vehicle operation by multiplying the reduction in the number of gallons of fuel consumed by the carbon content per gallon of fuel and the ratio of carbon dioxide emissions per unit of carbon consumed during the combustion process.[17]

Direct or "tailpipe" carbon dioxide emissions occurring during year t as a result of fuel consumption by vehicles of model k produced during model year MY are calculated from MW_{CO2}/MW_C, where c_f indicates the carbon content (by weight) per gallon of fuel, and MW_{CO2} and MW_C are the molecular weights of carbon dioxide (44) and carbon (12). This calculation is performed separately for carbon dioxide emissions resulting from gasoline and diesel fuel combustion, since their carbon content per gallon differs. The carbon content of gasoline used in the CAFE model is a weighted average of those for different types of gasoline in use.

As with fuel consumption, the effect of a new CAFE standard on carbon dioxide emissions from vehicle operation is measured by the difference in emissions with the new standard in effect, and those under a baseline or other alternative standard. Denoting these CAFE$_1$ and CAFE$_0$ as previously, the change in carbon dioxide emissions from fuel consumed by vehicles of model k and model year MY during year t is:

$$C^{tp}_{k,MY,t,CAFE1} = \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) c_f \, (MW_{CO2}/MW_C) \qquad (23)$$

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

Increasing the stringency of CAFE standards will also affect carbon dioxide emissions generated from combustion of fossil fuels used during petroleum extraction, transportation,

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[16] 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.

[17] 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).

storage, and refining, as well as during storage and distribution of refined fuel. Carbon dioxide emissions from each stage of the fuel production and distribution process are calculated using estimates of carbon dioxide emissions per unit of fuel energy. These estimates are converted to a per-gallon basis using the energy content per gallon of gasoline and diesel, and summed to calculate total carbon dioxide emissions per gallon of fuel used.

For vehicles of model k and model year MY, total carbon dioxide emissions during year t from fuel production, distribution, and use are calculated as:

$$C^{tot}_{k,MY,t} = g_{k,MY,t} \left(c_f + c_r + c_d \right) \qquad (24)$$

As above, c_f (a model input) is the carbon content of each fuel type, c_r includes carbon emissions per gallon during crude petroleum extraction, transportation, and refining, c_d represents carbon emissions per gallon during storage and distribution of refined fuel.

The effect of increasing a baseline standard CAFE$_0$ to a higher standard CAFE$_1$ on total carbon emissions from fuel production and use is:

$$C^{tot}_{k,MY,t,CAFE1} = \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) \left(c_f + r \cdot c_r + c_d \right) \qquad (25)$$

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

2.3.5 Air Pollutant Emissions

Stricter CAFE standards can result in higher or lower emissions of criteria air pollutants, by-products of fuel combustion that are emitted by internal combustion engines as well as during fuel production 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.

The increased use of vehicle models with improved fuel economy that occurs through the rebound effect causes increased emissions of criteria pollutants, since federal standards regulate permissible emissions of these pollutants on a per-mile basis. The increases in emissions of these pollutants during vehicle operation are estimated by multiplying the increase in total miles driven by vehicles whose fuel economy is improved by their per-mile emission rates for each pollutant.

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

$$E^{tp}_{i,k,MY,t} = \left(M_{k,MY,t} - \Delta M_{k,MY,t} \right) e_{i,k,a} \qquad (26)$$

where ($M_{k,MY,t} + M_{k,MY,t}$) is given by (26), and $e_{i,ka,}$ is emissions per mile of pollutant i by vehicles of model k and model year m at age $a = t - MY$. Emission rates (model inputs) for criteria air pollutants differ by vehicle type, size class, model year of production, and age.

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.[18] 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 within the U.S. from producing and distributing each type of fuel consumed by vehicles of model k and vintage MY during year t are:

$$E_{i,k,MY,t}^{up} = g_{k,MY,t}\left(r \cdot e_{i,r} - e_{i,d}\right)$$ (27)

where $g_{k,MY,t}$ is calculated from (27), 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 a 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:

$$E_{i,k,MY,t}^{tot} = E_{i,k,MY,t}^{tp} + E_{i,k,MY,t}^{up}$$ (28)

In turn, the effect on criteria pollutant emissions of a proposed increase to a standard CAFE$_1$ a baseline standard of CAFE$_0$ is

$$\begin{aligned}E_{i,k,MY,t,CAFE1}^{tot} = &\left(\Delta M_{k,MY,t,CAFE1} - \Delta M_{k,MY,t,CAFE0}\right)e_{i,k,MY,t}\\ &+\left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right)\left(r \cdot e_{i,r} + e_{i,d}\right)\end{aligned}$$ (29)

Again, 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 may potentially 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. Of course, the likelihood that this will occur this also depends on the magnitude of the rebound effect itself. For other pollutants, however, emission rates during fuel production are large relative to those

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[18] Reductions in criteria pollutant emissions from fuel refining and distribution are calculated using input values specifying emission rates. Argonne National Laboratories' GREET model is an available source of such inputs; 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.

from vehicle operation, so on balance, emissions of these pollutants are likely to decline as CAFE standards are raised.

2.3.6   Private versus Social Costs and Benefits

Improving the fuel efficiency of new vehicles produces a wide range of benefits and costs, many of which affect buyers of those vehicles directly. 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 cost 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 that society or the U.S. economy attaches to saving fuel 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.

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 A.3 provides examples of specific unit economic values and other parameters used to estimate the aggregate value of these various benefits and costs, explains how these sample values were derived, and reports the specific sources from which they were obtained.

2.3.6.1   Benefits and Costs to New Vehicle Buyers:
2.3.6.1.1   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 buyers of vehicle 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.

2.3.6.1.2   The Value of Fuel Savings

The CAFE modeling system estimates the economic value of fuel savings to buyers of new vehicle models whose fuel economy is improved by applying the forecast (an input to the model) of future retail 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 (an input to the model) they expect to own a new vehicle, and that they discount these expected savings to the year in which they purchase new vehicles.

2.3.6.1.3   Benefits from Additional Driving

The rebound effect also 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 to them—which has been reduced by improved fuel economy—represents the increase in consumer surplus associated with additional rebound effect driving.

The system estimates the value of these benefits using the conventional approximation of one half of the product of the decline in fuel cost per mile driven and the resulting increase in the annual number of miles 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. Given typical input values (*e.g*, for fuel prices), this benefit is relatively small by comparison to most other economic impacts of raising CAFE standards.

2.3.6.1.4   The Value of Extended Refueling Range

Manufacturers' efforts to improve the fuel economy of selected new vehicle models will also increase their driving range per tank of fuel. 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.[19] No direct estimates of the value of extended vehicle range are readily available, so the CAFE model 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.

2.3.6.1.5   Changes in Performance and Utility

The system currently assumes that the costs and effects of fuel-saving technologies reflect the application of these technologies in a manner that holds vehicle performance and utility constant.   Therefore, the system currently does not estimate changes in vehicle performance or utility.

2.3.6.1.6   Social Benefits and Costs from Increased Fuel Economy
2.3.6.1.6.1   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 payments of state and federal taxes by purchasers of fuel will be exactly offset by reduced spending on the construction and maintenance of streets and highways that fuel taxes are mainly 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.

2.3.6.1.6.2   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

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[19] 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.

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 can reduce petroleum imports, and thus reduce these social costs to the extent that their magnitude varies with the volume of U.S. oil imports. Any reduction in their magnitude represents an additional category of economic benefits from tighter fuel economy standards.

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.

2.3.6.1.6.3 Valuing Changes in Environmental Impacts

The CAFE modeling system estimates the economic value of the net change in emissions of criteria pollutants, including carbon monoxide, volatile organic compounds, nitrogen oxides, sulfur dioxide, and fine particulates, using estimates of the economic damage costs per ton of emissions of each of these pollutants. As indicated previously, emissions of criteria pollutants can rise or fall when fuel economy increases, so the economic costs of these emissions can increase or decline in response to higher CAFE standards.

The model estimates changes in damage costs caused by carbon dioxide emissions by multiplying the magnitude of the change in emissions by the estimated value of damages per unit of emissions.

2.3.6.1.7 Social Costs of Added Driving

In addition to increasing emissions of criteria pollutants, any 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 driving 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. Finally, added vehicle use from the rebound effect may also increase traffic noise, which causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, pedestrians and other bystanders, and residents or occupants of surrounding property.

The CAFE modeling system uses estimates of the increases in external costs – that is, the marginal social costs – from added congestion, property damages and injuries in traffic accidents, and noise levels caused by additional vehicle usage. It does so by applying estimates of the increases in these costs that result from each added mile of travel by different types of vehicles (passenger and nonpassenger automobiles) to the increase in the total number of miles driven projected to result from the rebound effect.

Appendix A   Model Inputs

The CAFE Compliance and Effects Modeling System utilizes a set of data files used as input to the analysis. All input files are specified in Microsoft® Excel format and are outline in Table 5 below. The user can define and edit all inputs to the system. For example, the system does not require market data constructed using confidential business information.

Table 5. Input Files

Input File	Contents
Market Data (Manufacturers Worksheet)	Contains an indexed list of manufacturers available during the study period, along with manufacturer's willingness to pay fines and other manufacturer-specific modeling settings.
Market Data (Vehicles Worksheet)	Contains an 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)	Contains an 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)	Contains an indexed list of transmissions available during the study period, along with various transmission attributes and optional settings related to technology applicability.
Technologies	Specifies estimates of the availability, cost, and effectiveness of various technologies, specific to various vehicle categories.
Parameters	Provides inputs used to calculate travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions, and economic externalities related to highway travel and petroleum consumption.
Emissions Rates	Provides inputs used to project the emissions rates of various pollutants.
Scenarios	Specifies coverage, structure, and stringency of CAFE standards for scenarios to be simulated.
EIS Parameters	Provides inputs required for EIS upstream emissions calculations. This input file is required for EIS modeling only.
EIS Tailpipe Emissions	Provides inputs required for EIS tailpipe emissions calculations. This input file is required for EIS modeling only.

Appendix A.1   Market Data File

The market data file contains four worksheets: Manufacturers, Vehicles, Engines and Transmissions. Taken together, the manufacturers, vehicle models, engines, and transmissions worksheets provide "initial state" historical and/or forecast data for the light vehicle fleet. The sections below describe each worksheet in greater detail.

Appendix A.1.1   Manufacturers Worksheet

The manufacturers input worksheet contains a list of all manufacturers that produce vehicle models offered for sale during the study period. Each manufacturer has a unique code and is represented by a unique manufacturer name. For each manufacturer, the manufacturer code, name, cost allocation strategy, and willingness to pay CAFE fines must all be specified. Available credits, if applicable, should be expressed in Vehicle/MPG and is applied directly as a credit (or discredit if negative) to the CAFE level for the given manufacturer in the given model year. If no available credits are to be specified, a value of zero (0.0) can be used or the cell can be left blank.

Table 6. Manufacturers Worksheet

Category	Column	Units	Definition/Notes
General	Manufacturer Code	integer	Unique number assigned to each manufacturer.
	Manufacturer Name	text	Name of the manufacturer.
	Cost Allocation Strategy	integer	The cost allocation strategy the manufacturer will use for allocating costs. 0 = allocate technology costs on an as-incurred basis 1 = distribute technology costs and fines based on the share of aggregate sales revenue 2 = not used 3 = distribute technology costs and fines evenly
	Discount Rate	number	Represents the manufacturer specific discount rate, which factors into the effective cost calculation.
	Optimize	text	Y = consider the manufacturer during optimization N = do not consider the manufacturer during optimization
Willingness to Pay CAFE Fines	2011	text	Represents the manufacturer's willingness to pay fines. Y = pay fines instead of applying ineffective technologies N = apply ineffective technologies instead of paying fines
	2012	text	
	2013	text	
	2014	text	
	2015	text	
	2016	text	
Available Domestic Auto Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Domestic Automobiles.
	2012	vehicle-mpg	
	2013	vehicle-mpg	
	2014	vehicle-mpg	
	2015	vehicle-mpg	
	2016	vehicle-mpg	
Available Imported Auto Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Imported Automobiles.
	2012	vehicle-mpg	
	2013	vehicle-mpg	
	2014	vehicle-mpg	
	2015	vehicle-mpg	
	2016	vehicle-mpg	
Available Light Truck Credits (mpg)	2011	vehicle-mpg	Represents the manufacturer's available credits towards CAFE compliance for vehicles regulated as Light Trucks.
	2012	vehicle-mpg	
	2013	vehicle-mpg	
	2014	vehicle-mpg	
	2015	vehicle-mpg	
	2016	vehicle-mpg	
Credits Apply to Baseline		text	Y = apply manufacturer's credits to the baseline scenario N = do not apply manufacturer's credits to the baseline scenario

Appendix A.1.2   Vehicles Worksheet

The vehicles 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. Data in **Table 7**, **Table 8**, and **Table 9** list the different columns of information specified in the vehicle models file. To make the information readable, the Vehicle Models tables are presented vertically and divided into sections.

In the "General" category, the vehicle code, manufacturer, model, nameplate, fuel economy, engine code, transmission code, and origin 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 engines and transmissions worksheets. 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 that would affect fuel economy (e.g., a different engine or transmission) – are specified by creating a new row (effectively a new vehicle model) with the older model's number in the "predecessor" field. The known or projected MSRP should be specified in its corresponding section for each model year in which the vehicle model is offered for sale. In the "Regulatory Classification" section, the regulatory and technology class assignments for each vehicle must be specified.

Table 7. Vehicles Worksheet (1)

Category	Column	Units	Definition/Notes
General	Vehicle Code	integer	Unique number assigned to each vehicle.
	Manufacturer	text	The manufacturer of the vehicle.
	Model	text	Name of the vehicle model.
	Nameplate	text	The nameplate of the vehicle.
	Primary Fuel	text	Most common type of fuel with which the vehicle's engine is compatible.
	Fuel Economy on Primary Fuel	mpg	Weighted (FTP+highway) fuel economy of the vehicle.
	Engine Code	integer	The engine code of the engine that the vehicle uses.
	Transmission Code	integer	The transmission code of the transmission that the vehicle uses.
	Origin	text	D = domestic; I = imported
Sales	MY2011	units	Vehicle's projected production for sale in the US.
	MY2012	units	
	MY2013	units	
	MY2014	units	
	MY2015	units	
	MY2016	units	
MSRP	MY2011	dollars	Vehicle's projected average MSRP (sales-weighted, including options).
	MY2012	dollars	
	MY2013	dollars	
	MY2014	dollars	
	MY2015	dollars	
	MY2016	dollars	
Regulatory Classification	Regulatory Class	text	The regulatory assignment of the vehicle. PC = the vehicle should be regulated as a passenger automobile LT = the vehicle should be regulated as a light truck
	Technology Class	text	The technology class of the vehicle.

Within the "Vehicle" category, it is important that each vehicle model's class, style, structure, drive, footprint, curb weight, GVWR, and fuel capacity be specified. For any hybrid vehicle models, it is necessary to specify the type of hybridization as well. In the "Planning & Assembly" section, it is important that the number of any (single) predecessor to the current vehicle model be specified. The redesign and refresh years must be comma separated and contain all known previous and projected future redesign and refresh years.

Table 8. Vehicles Worksheet (2)

Category	Column	Units	Definition/Notes
Vehicle Information	Class	text	Vehicle class.
	Style	text	Vehicle style.
	Structure	text	Vehicle structure (e.g., ladder or unibody).
	Drive	text	Vehicle drive (e.g., A=all-wheel drive, F=front-wheel drive, R=rear-wheel drive, 4=four-wheel drive).
	Footprint	sq. feet	The vehicle footprint; wheelbase times average track width.
	Curb Weight	pounds	Total weight of the vehicle, including batteries, lubricants, and other expendable supplies, but excluding the driver, passengers, and other payloads (SAE J1100).
	GVWR	pounds	Gross Vehicle Weight Rating; weight of loaded vehicle, including passengers and cargo.
	Seating (Max)	integer	The number of usable seat belts before folding and removal of seats (where accomplished without specific tools).
	Fuel Capacity	gallons	The capacity of the vehicle's fuel tank in gallons of diesel fuel or gasoline; MJ (LHV) of other fuels (or chemical battery energy).
Hybridization	Type of Hybrid/Electric Vehicle	text	Hybridization type of the vehicle, if any.
Planning and Assembly	Predecessor	integer	The vehicle code of a vehicle model upon which this vehicle model is based.
	Refresh Years	model year	Comma separated list of previous and future refresh years of the vehicle.
	Redesign Year	model year	Comma separated list of previous and future redesign years of the vehicle.

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" category. This section must be completed to prevent double counting of technologies.

Table 9. Vehicles Worksheet (3)

Category	Column	Units	Definition/Notes
Technology Applicability	EPS	text	
	IACC	text	
	MHEV	text	
	BISG	text	
	CISG	text	
	PSHEV	text	
	2MHEV	text	<blank> = the technology is not used on the vehicle
	PHEV	text	USED = the technology is used on the vehicle
	MS1	text	SKIP = the technology is not applicable to the vehicle
	MS2	text	
	MS5	text	
	ROLL	text	
	LDB	text	
	SAXU	text	
	SAXL	text	
	AERO	text	

Appendix A.1.3 Engines Worksheet

Similar to the vehicles input sheet, the engines 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 on the vehicles worksheet. For each engine, the engine code, manufacturer, configuration, primary fuel, cycle, aspiration, valve actuation/timing, valve lift, number of cylinders, number of valves per cylinder, and horsepower must all be specified. As in the vehicles worksheet, the technology applicability for any engine technology must be specified for any specific engine.

Table 10. Engines Worksheet

Category	Column	Units	Definition/Notes
General	Engine Code	integer	Unique number assigned to each engine.
	Manufacturer	text	The manufacturer of the engine.
	Configuration	text	Configuration of the engine.
	Primary Fuel	text	Most common type of fuel with which the engine is compatible.
	Engine Oil Viscosity	text	Ratio between the applied shear stress and the rate of shear, which measures the resistance of flow of the engine oil (as per SAE Glossary of Automotive Terms).
	Cycle	text	Combustion cycle of the engine.
	Fuel Delivery System	text	The mechanism that delivers fuel to the engine.
	Aspiration	text	Breathing or induction process of the engine (as per SAE Automotive Dictionary).
	Valvetrain Design	text	Design of the total mechanism from camshaft to valve of an engine that actuates the lifting and closing of a valve (as per SAE Automotive Dictionary).
	Valve Actuation/Timing	text	Valve opening and closing points in the operating cycle (SAE J604).
	Valve Lift	text	The manner in which the valve is raised during combustion (as per SAE Automotive Dictionary).
	Cylinders	integer	Number of engine cylinders.
	Valves/Cylinder	integer	Number of valves per cylinder.
	Deactivation	text	Weighted (FTP+highway) aggregate degree of deactivation.
	Displacement	liters	Total volume displaced by a piston in a single stroke.
	Max. Horsepower	number	Maximum horsepower of the engine (horsepower).
	Max. Torque	number	Maximum torque of the engine (pound-foot).
Technology Applicability	LUB	text	
	EFR	text	
	CCPS	text	
	DVVLS	text	
	DEACS	text	
	ICP	text	
	DCP	text	
	DVVLD	text	
	CVVL	text	\<blank\> = the technology is not used on the engine
	DEACD	text	USED = the technology is used on the engine
	DEACO	text	SKIP = the technology is not applicable to the engine
	CCPO	text	
	DVVLO	text	
	CDOHC	text	
	SGDI	text	
	CBRST	text	
	TRBDS	text	
	EGRB	text	
	DSLT	text	
	DSLC	text	

Appendix A.1.4   Transmissions Worksheet

Similar to the vehicles and engines input sheets, the transmissions 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 on the vehicles worksheet. For each transmission, the transmission code, manufacturer, type, and number of forward gears must all be specified. As in the vehicles worksheet, the technology applicability for any engine technology must be specified for any specific transmission.

Table 11. Transmissions Worksheet

Category	Column	Units	Definition/Notes
General	Transmission Code	integer	Unique number assigned to each transmission.
	Manufacturer	text	The manufacturer of the transmission.
	Type	text	Type of the transmission.
	Number of Forward Gears	integer	Number of forward gears the transmission has.
Technology Applicability	6MAN	text	
	IATC	text	<blank> = the technology is not used on the transmission
	CVT	text	USED = the technology is used on the transmission
	NAUTO	text	SKIP = the technology is not applicable to the transmission
	DCTAM	text	

Appendix A.2   Technologies File

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 technology classes: subcompact cars, subcompact performance cars, compact cars, compact performance cars, midsize cars, midsize performance cars, large cars, large performance cars, minivans, small pickups and SUVs, midsize pickups and SUVs, and large pickups and SUVs. **Table 12** shows sample technology assumptions for subcompact cars.

Table 12. Technologies Assumptions (Sample)

Subcompact PC					Benefit/Cost Variables											Phase-in Values					
Index	Technology	Abbr.	TechType	Year Avail.	FC-Lower	FC-Upper	Cost-Lower	Cost-Upper	Learning Type	Learning Start	Learning End	Learning Threshold	Learning Rate	Aux.	Applicability	Phase-in 2011	Phase-in 2012	Phase-in 2013	Phase-in 2014	Phase-in 2015	Phase-in 2016
1	Low Friction Lubricants	LUB	EngMod	2007	0.50%	0.50%	$ 3	$ 3							TRUE	85%	100%	100%	100%	100%	100%
2	Engine Friction Reduction	EFR	EngMod	2007	1.00%	2.00%	$ 13	$ 13						1	TRUE	85%	85%	85%	85%	100%	100%
3	VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	EngMod	2007	1.00%	3.00%	$ 45	$ 45	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
4	Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	EngMod	2007	1.00%	3.00%	$ 142	$ 142	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
5	Cylinder Deactivation on SOHC	DEACS	EngMod	2007	0.00%	0.00%	$ -	$ -	TIME	2012			0.03		FALSE	85%	85%	85%	85%	85%	85%
6	VVT - Intake Cam Phasing (ICP)	ICP	EngMod	2007	1.00%	2.00%	$ 45	$ 45	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
7	VVT - Dual Cam Phasing (DCP)	DCP	EngMod	2007	2.00%	3.00%	$ 38	$ 38	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
8	Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	EngMod	2007	1.00%	3.00%	$ 142	$ 142	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
9	Continuously Variable Valve Lift (CVVL)	CVVL	EngMod	2007	1.50%	3.50%	$ 277	$ 277	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
10	Cylinder Deactivation on DOHC	DEACD	EngMod	2007	0.00%	0.00%	$ -	$ -	TIME	2012			0.03		FALSE	85%	85%	85%	85%	85%	85%
11	Cylinder Deactivation on OHV	DEACO	EngMod	2007	0.00%	0.00%	$ -	$ -	TIME	2012			0.03		FALSE	85%	85%	85%	85%	85%	85%
12	VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	EngMod	2007	1.00%	1.50%	$ 45	$ 45	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
13	Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	EngMod	2007	0.50%	2.50%	$ 142	$ 142	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
14	Conversion to DOHC with DCP	CDOHC	EngMod	2007	1.00%	2.50%	$ 276	$ 276	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	85%	85%
15	Stoichiometric Gasoline Direct Injection (GDI)	SGDI	EngMod	2007	2.00%	3.00%	$ 59	$ 59	TIME	2012			0.03	1	TRUE	85%	85%	85%	85%	100%	100%
16	Combustion Restart	CBRST	EngMod	2007	2.00%	2.50%	$ 118	$ 118	TIME	2014			0.03		TRUE	0%	0%	0%	85%	85%	85%
17	Turbocharging and Downsizing	TRBDS	EngMod	2007	4.23%	4.81%	$ 445	$ 445	TIME	2012			0.03		TRUE	85%	85%	85%	85%	85%	85%
18	Exhaust Gas Recirculation (EGR) Boost	EGRB	EngMod	2007	3.50%	4.00%	$ 144	$ 144	TIME	2013			0.03		TRUE	0%	0%	85%	85%	85%	85%
19	Conversion to Diesel following CBRST	DSLC	EngMod	2007	13.94%	13.45%	$ 1,527	$ 1,527	TIME	2012			0.03		TRUE	0%	3%	6%	9%	12%	15%
20	Conversion to Diesel following TRBDS	DSLT	EngMod	2007	6.88%	5.29%	$ 938	$ 938	TIME	2012			0.03		TRUE	0%	3%	6%	9%	12%	15%
21	6-Speed Manual/Improved Internals	6MAN	TrMod	2007	0.50%	0.50%	$ 250	$ 250	TIME	2012			0.03		TRUE	85%	85%	85%	85%	100%	100%
22	Improved Auto. Trans. Controls/Externals	IATC	TrMod	2007	1.50%	2.50%	$ 60	$ 60	TIME	2012			0.03		TRUE	85%	85%	85%	85%	100%	100%
23	Continuously Variable Transmission	CVT	TrMod	2007	0.70%	2.00%	$ 250	$ 250	TIME	2012			0.03		TRUE	85%	85%	85%	85%	85%	85%
24	6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	TrMod	2007	1.40%	3.40%	$ 112	$ 112	TIME	2012			0.03		TRUE	85%	85%	100%	100%	100%	100%
25	Dual Clutch or Automated Manual Transmission	DCTAM	TrMod	2007	5.50%	7.50%	$ (59)	$ (59)	TIME	2012			0.03		TRUE	85%	85%	100%	100%	100%	100%
26	Electric Power Steering	EPS	ELEC	2007	1.00%	2.00%	$ 106	$ 106	TIME	2012			0.03		TRUE	85%	85%	85%	85%	100%	100%
27	Improved Accessories	IACC	ELEC	2007	1.00%	2.00%	$ 128	$ 128	TIME	2012			0.03		TRUE	85%	85%	85%	85%	100%	100%
28	12V Micro-Hybrid	MHEV	ELEC	2007	2.00%	3.00%	$ 288	$ 288	TIME	2012			0.03		TRUE	85%	85%	85%	85%	85%	85%
29	Belt mounted Integrated Starter Generator	BISG	ELEC	2007	4.00%	6.00%	$ 286	$ 286	VOLUME			150,000	0.2		TRUE	85%	85%	85%	85%	85%	85%
30	Crank mounted Integrated Starter Generator	CISG	ELEC	2007	8.90%	8.64%	$ 2,791	$ 2,791	VOLUME			150,000	0.2		TRUE	0%	3%	6%	9%	12%	15%
31	Power Split Hybrid	PSHEV	ELEC	2007	6.28%	12.35%	$ 1,600	$ 1,600	VOLUME			150,000	0.2		TRUE	0%	3%	6%	9%	12%	15%
32	2-Mode Hybrid	2MHEV	ELEC	2007	0.12%	3.87%	$ 3,248	$ 3,248	VOLUME			150,000	0.2		FALSE	0%	3%	6%	9%	12%	15%
33	Plug-in Hybrid	PHEV	ELEC	2011	45.23%	47.67%	$11,520	$11,520	VOLUME			150,000	0.2		TRUE	0%	3%	6%	9%	12%	15%
34	Material Substitution (1.50%)	MS1	MSM	2007	0.53%	0.53%	$ 1	$ 1						1.50%	TRUE	85%	85%	85%	85%	85%	100%
35	Material Substitution (5% to 10% Cum)	MS2	MSM	2014	2.74%	2.74%	$ 1	$ 1						3.50%	TRUE	85%	85%	85%	85%	85%	100%
36	Material Substitution (NA)	MS5	MSM	2007	0.00%	0.00%	$ -	$ -						0.00%	FALSE	85%	85%	85%	85%	85%	100%
37	Low Rolling Resistance Tires	ROLL	DLR	2007	1.00%	2.00%	$ 6	$ 6							TRUE	85%	85%	85%	85%	100%	100%
38	Low Drag Brakes	LDB	DLR	2007	0.50%	1.00%	$ 63	$ 63							FALSE	85%	85%	85%	85%	100%	100%
39	Secondary Axle Disconnect - Unibody	SAXU	DLR	2007											FALSE	85%	85%	85%	85%	100%	100%
40	Secondary Axle Disconnect - Ladder Frame	SAXL	DLR	2007	1.00%	1.50%	$ 87	$ 87	TIME	2012			0.03		TRUE	85%	85%	85%	85%	100%	100%
41	Aero Drag Reduction	AERO	AERO	2007	2.00%	3.00%	$ 48	$ 48	TIME	2012			0.03		TRUE	85%	85%	85%	85%	100%	100%

For each technology, Table 12 contains the following:

- *Index*: Specifies the index of the technology, which loosely reflects the sequence to follow when populating technology groups.

- *Technology*: Represents the full technology name.

- *Abbr.*: Represents the technology abbreviation used in output files.

- *TechType*: Specifies the technology group to which the technology belongs.

- *Year Avail.*: Specifies the first year the technology is available for applicability.

- *FC-Lower*: Provides a low-end estimate of the incremental fuel consumption reduction.

- *FC-Upper*: Provides a high-end estimate of the incremental fuel consumption reduction.

- *Cost-Lower*: Provides a low-end estimate of the incremental cost (RPE in 2003 dollars, or dollars/pound for material substitution).

- *Cost-Upper*: Provides a high-end estimate of the incremental cost (RPE in 2003 dollars, or dollars/pound for material substitution).

- *Learning Type*: Indicates whether to apply time-based or volume-based learning curve when estimating the technology costs. If this value is blank, the technology does not use a learning curve.

- *Learning Start*: Specifies the model year when learning begins for a Technology.

- *Learning End*: Not applicable; reserved for future use.

- *Learning Threshold*: Indicates the minimum sales volume the industry must reach before learning for the technology begins. The learning threshold applies to volume-based learning only.

- *Learning Rate*: Specifies the rate of decline to apply to the learning curve.

- *Aux.*: For material substitution technologies, specifies the relative change in curb weight; not applicable to other technologies.

- *Applicability*: Indicates whether the technology is available for applicability on a given technology class.

- *Phase-in Values*: Specifies the maximum incremental share of a manufacturer's fleet to which technology can be added in model years 2011 to 2016; the phase-in value for each year is cumulative over the entire analysis period.

The technologies are organized into technology types specified by TechType field in the fourth column. Each technology type is populated with specific technologies following the sequence specified by the Index column. The sequence of engine and transmission technologies may be split to follow slightly different paths, based on the original vehicle, engine, or transmission characteristics, or depending on which technologies have already been applied to a vehicle. If the original vehicle uses a manual transmission with fewer than six gears, the only available technology would be the 6-speed manual transmission. If the original vehicle, however, uses an automatic transmission, the technologies applied

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would follow one of the two specified orders: IATC and CVT; or: IATC, 6/7/8-speed auto (NAUTO), and dual clutch / automatic manual transmission (DCTAM).

Appendix A.2.1   Technology Synergies

Technology synergies occur when the combined effect of two technologies is greater than (or less than) the fuel consumption reduction for the two technologies combined. To support synergies, the technology input file has synergy sections for cost and fuel improvements. Samples from the synergy tables are shown in Table 13 and Table 14 below.

The synergy table is most commonly used for synergistic interactions in vehicle technologies from differing technology groups (e.g. between engine technologies and transmission technologies). Synergies within a technology group are already built into the cost and fuel reduction values for the technologies. Therefore, in-group synergies are not likely to occur, unless special circumstances arise, such as branching of technology paths.

Table 13. Technology Cost Synergies (Sample)

Synergies			Synergy values by Vehicle Class Vehicle classes must be in the same order and the same names as the preceeding worksheets. Positive values are increase costs, negative values are decrease costs. Blank cells are assumed to be zero.											
Type	Technology A	Technology B	Subcompact PC	Subcompact Perf. PC	Compact PC	Compact Perf. PC	Midsize PC	Midsize Perf. PC	Large PC	Large Perf. PC	Minivan LT	Small LT	Midsize LT	Large LT
Accounting	MHEV	CBRST	$ (118)	$ (118)	$ (118)	$ (118)	$ (118)	$ (118)	$(118)	$ (118)	$ (118)	$(118)	$ (118)	$(118)
Accounting	DEACD	CVVL	$ -	$ -	$ -	$ (28)	$ -	$ (28)	$ (28)	$ (28)	$ (28)	$ -	$ (28)	$ (28)
Accounting	PSHEV	DCTAM	$ 197	$ 95	$ 197	$ 95	$ 146	$ 95	$ 146	$ 95	$ 146	$ 146	$ 95	$ 95
Accounting	PHEV	DCTAM	$ 197	$ 95	$ 197	$ 95	$ 146	$ 95	$ 146	$ 95	$ 146	$ 8	$ 95	$ 95
Accounting	TRBDS	DVVLD	$ (4)	$ (4)	$ (4)	$ (197)	$ (4)	$ (197)	$(197)	$ (274)	$ (197)	$ (4)	$ (197)	$(274)
Accounting	TRBDS	CVVL	$ (4)	$ (4)	$ (4)	$ (197)	$ (4)	$ (197)	$(197)	$ (274)	$ (197)	$ (4)	$ (197)	$(274)
Accounting	TRBDS	DVVLO	$ 141	$ 141	$ 141	$ 479	$ 141	$ 479	$ 479	$ 282	$ 479	$ 141	$ 479	$ 282
Accounting	TRBDS	CDOHC	$ (4)	$ (4)	$ (4)	$ (197)	$ (4)	$ (197)	$(197)	$ (274)	$ (197)	$ (4)	$ (197)	$(274)
Accounting	DSLC	DVVLD	$ (38)	$ (38)	$ (38)	$ (83)	$ (38)	$ (83)	$ (83)	$ (83)	$ (83)	$ (38)	$ (83)	$ (83)
Accounting	DSLC	CVVL	$ (173)	$ (173)	$ (173)	$ (358)	$ (173)	$ (358)	$(358)	$ (317)	$ (358)	$(173)	$ (358)	$(317)
Accounting	DSLC	DVVLO	$ -	$ -	$ -	$ 80	$ -	$ 80	$ 80	$ 148	$ 80	$ -	$ 80	$ 148
Accounting	DSLC	CDOHC	$ (134)	$ (134)	$ (134)	$ (328)	$ (134)	$ (328)	$(328)	$ (376)	$ (328)	$(134)	$ (328)	$(376)
Accounting	DSLT	DVVLD	$ (34)	$ (34)	$ (34)	$ 114	$ (34)	$ 114	$ 114	$ 191	$ 114	$ (34)	$ 114	$ 191
Accounting	DSLT	CVVL	$ (169)	$ (169)	$ (169)	$ (162)	$ (169)	$ (162)	$(162)	$ (42)	$ (162)	$(169)	$ (162)	$ (42)
Accounting	DSLT	DVVLO	$ (141)	$ (141)	$ (141)	$ (399)	$ (141)	$ (399)	$(399)	$ (134)	$ (399)	$(141)	$ (399)	$(134)
Accounting	DSLT	CDOHC	$ (131)	$ (131)	$ (131)	$ (131)	$ (131)	$ (131)	$(131)	$ (102)	$ (131)	$(131)	$ (131)	$(102)

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Table 14. Technology Fuel Consumption Synergies (Sample)

Synergies			Fuel Consumption Improvement Synergy values by Vehicle Class. Vehicle classes must be in the same order and the same names as the preceeding worksheets. Positive values are [positive] synergies, negative values are dissynergies. Blank cells are assumed to be zero.										
Type	Technology A	Technology B	Subcompact PC	Subcompact Perf. PC	Compact PC	Compact Perf. PC	Midsize PC	Midsize Perf. PC	Large PC	Large Perf. PC	Minivan LT	Small LT	Midsize LT	Large LT
Accounting	MHEV	CBRST	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%	-2.25%
Accounting	DEACD	CVVL	0.00%	0.00%	0.00%	-0.25%	0.00%	-0.25%	-0.25%	-0.25%	-0.25%	0.00%	-0.25%	-0.25%
Accounting	PSHEV	DCTAM	-7.32%	-4.18%	-7.32%	-4.18%	-4.18%	-4.18%	-4.18%	-4.18%	-4.18%	-4.18%	-4.18%	-4.10%
Accounting	PHEV	DCTAM	-4.33%	-2.47%	-4.33%	-2.47%	-2.47%	-2.47%	-2.47%	-2.47%	-2.47%	-2.47%	-2.47%	-2.43%
Accounting	TRBDS	DVVLD	-1.95%	-1.95%	-1.95%	0.51%	-1.95%	0.51%	0.51%	0.51%	0.51%	-1.95%	0.51%	0.51%
Accounting	TRBDS	CVVL	-2.45%	-2.45%	-2.45%	0.25%	-2.45%	0.25%	0.25%	0.25%	0.25%	-2.45%	0.25%	0.25%
Accounting	TRBDS	DVVLO	1.21%	1.21%	1.21%	-0.74%	1.21%	-0.74%	-0.74%	-0.74%	-0.74%	1.21%	-0.74%	-0.74%
Accounting	TRBDS	CDOHC	0.97%	0.97%	0.97%	-0.99%	0.97%	-0.99%	-0.99%	-0.99%	-0.99%	0.97%	-0.99%	-0.99%
Accounting	DSLC	DVVLD	-1.76%	-1.76%	-1.76%	0.46%	-1.76%	0.46%	0.46%	0.46%	0.46%	-1.76%	0.46%	0.46%
Accounting	DSLC	CVVL	-2.21%	-2.21%	-2.21%	0.23%	-2.21%	0.23%	0.23%	0.23%	0.23%	-2.21%	0.23%	0.23%
Accounting	DSLC	DVVLO	1.09%	1.09%	1.09%	-0.67%	1.09%	-0.67%	-0.67%	-0.67%	-0.67%	1.09%	-0.67%	-0.67%
Accounting	DSLC	CDOHC	0.88%	0.88%	0.88%	-0.89%	0.88%	-0.89%	-0.89%	-0.89%	-0.89%	0.88%	-0.89%	-0.89%
Accounting	DSLT	DVVLD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	DSLT	CVVL	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	DSLT	DVVLO	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Accounting	DSLT	CDOHC	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Physical	CCPS	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Physical	CCPS	IATC	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
Physical	CCPS	CVT	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
Physical	CCPS	NAUTO	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
Physical	CCPS	MHEV	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
Physical	CCPS	BISG	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%	-0.9%
Physical	DVVLS	6MAN	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Physical	DVVLS	IATC	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
Physical	DVVLS	CVT	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%	-1.4%
Physical	DVVLS	NAUTO	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%
Physical	DVVLS	MHEV	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%
Physical	DVVLS	BISG	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
Physical	DEACS	6MAN	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%

For each technology relation, the above two tables contain the following:

- *Type*: Specifies the synergy type relation between two technologies. The "accounting" type indicates that the synergy relation between two technologies is to provide accounting adjustments for the decision trees and is the only synergy type applied to technology costs. The "physical" type indicates that the synergy relation between two technologies is to address physical energy losses.

- *Technology A*: Specifies the abbreviation of the first technology in a synergy pair.

- *Technology B*: Specifies the abbreviation of the second technology in a synergy pair.

- *Subcompact PC – Large LT*: Contains values to offset the technology cost or fuel consumption when either of technology **A** or **B** is being applied when the other is already installed.

When a technology is being applied (or is being tested for application), a lookup is performed in the "Technology A" and "Technology B" columns of the table. If found, the vehicle is examined to determine if the paired technology (or technologies) have been applied (or are installed as part of the base vehicle definition). If so, the offset value for the applicable vehicle class is obtained, summed, and applied to the cost or fuel consumption reduction of the technology being examined.

Appendix A.2.2   Technology Variations for Monte-Carlo

During Monte-Carlo modeling, it is necessary to specify technology FC and cost variations, so that the model may properly assign randomized values to technology costs and fuel consumption improvements. Table 15 below provides an example of technology variations used during Monte-Carlo modeling.

Table 15. Technology FC and Cost Variations for Monte-Carlo Modeling (Sample)

	Technology FC and Cost Variations for Monte-Carlo Modeling					
Index	Technology	Abbr.	TechType	Complexity	FC	Cost
1	Low Friction Lubricants	LUB	EngMod	L	29.00%	15.50%
2	Engine Friction Reduction	EFR	EngMod	L	33.33%	15.50%
3	VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	EngMod	L	50.00%	15.50%
4	Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	EngMod	L	50.00%	15.50%
5	Cylinder Deactivation on SOHC	DEACS	EngMod	L	9.09%	15.50%
6	VVT - Intake Cam Phasing (ICP)	ICP	EngMod	L	33.33%	15.50%
7	VVT - Dual Cam Phasing (DCP)	DCP	EngMod	L	20.00%	15.50%
8	Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	EngMod	L	50.00%	15.50%
9	Continuously Variable Valve Lift (CVVL)	CVVL	EngMod	H	40.00%	46.50%
10	Cylinder Deactivation on DOHC	DEACD	EngMod	L	100.00%	15.50%
11	Cylinder Deactivation on OHV	DEACO	EngMod	L	17.02%	15.50%
12	VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	EngMod	L	20.00%	15.50%
13	Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	EngMod	L	66.67%	15.50%
14	Conversion to DOHC with DCP	CDOHC	EngMod	L	42.86%	15.50%
15	Stoichiometric Gasoline Direct Injection (GDI)	SGDI	EngMod	L	20.00%	15.50%
16	Combustion Restart	CBRST	EngMod	M	29.00%	31.00%
17	Turbocharging and Downsizing	TRBDS	EngMod	M	29.00%	31.00%
18	Exhaust Gas Recirculation (EGR) Boost	EGRB	EngMod	M	29.00%	31.00%
19	Conversion to Diesel following CBRST	DSLC	EngMod	M	29.00%	31.00%
20	Conversion to Diesel following TRBDS	DSLT	EngMod	M	29.00%	31.00%
21	6-Speed Manual/Improved Internals	6MAN	TrMod	L	29.00%	15.50%
22	Improved Auto. Trans. Controls/Externals	IATC	TrMod	L	25.00%	15.50%
23	Continuously Variable Transmission	CVT	TrMod	M	48.15%	31.00%
24	6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	TrMod	L	41.67%	15.50%
25	Dual Clutch or Automated Manual Transmission	DCTAM	TrMod	M	29.00%	31.00%
26	Electric Power Steering	EPS	ELEC	L	33.33%	15.50%
27	Improved Accessories	IACC	ELEC	M	33.33%	31.00%
28	12V Micro-Hybrid	MHEV	ELEC	M	29.00%	31.00%
29	Belt mounted Integrated Starter Generator	BISG	ELEC	M	29.00%	31.00%
30	Crank mounted Integrated Starter Generator	CISG	ELEC	H	29.00%	46.50%
31	Power Split Hybrid	PSHEV	ELEC	H	32.57%	46.50%
32	2-Mode Hybrid	2MHEV	ELEC	H	41.66%	46.50%
33	Plug-in Hybrid	PHEV	ELEC	H	29.00%	46.50%
34	Material Substitution (1.50%)	MS1	MSM	L	29.00%	15.50%
35	Material Substitution (5% to 10% Cum)	MS2	MSM	L	29.00%	15.50%
36	Material Substitution (NA)	MS5	MSM	L	29.00%	15.50%
37	Low Rolling Resistance Tires	ROLL	DLR	L	33.33%	15.50%
38	Low Drag Brakes	LDB	DLR	L	33.33%	15.50%
39	Secondary Axle Disconnect - Unibody	SAXU	DLR	L	29.00%	15.50%
40	Secondary Axle Disconnect - Ladder Frame	SAXL	DLR	L	20.00%	15.50%
41	Aero Drag Reduction	AERO	AERO	L	20.00%	15.50%

The first four columns in the above table are used to identify and match the associated technologies on the vehicle technology class tabs. The rest are used as follows:

- *Complexity*: Indicates the complexity level of the Technology.

- *FC*: Specifies the variation of the fuel consumption estimate of a technology.

- *Cost*: Specifies the variation of the cost estimate of a technology.

Appendix A.3   Parameters File

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.

Appendix A.3.1   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 16. Vehicle Age Data Worksheet (sources data shown as samples)

Model Characteristic	Units	Definition/Notes	Source
Proportion of Original Sales Surviving to Age	proportion	Proportion of original vehicle sales that remain in service by vehicle age (year 1 to 26 for cars, 1 - 36 for trucks)	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.
Segment-Based Average Annual Miles Driven	miles	Average annual miles driven by surviving vehicles by vehicle age (year 1 to 26 for cars, 1 - 36 for trucks)	
Miles Driven at Low Fuel Prices	miles	Annual miles driven at low fuel prices by surviving vehicles by vehicle age (year 1 to 26 for cars, 1 - 36 for trucks)	
Miles Driven at High Fuel Prices	miles	Annual miles driven at high fuel prices by surviving vehicles by vehicle age (year 1 to 26 for cars, 1 - 36 for trucks)	

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 35 years for light trucks), by which time only a small fraction typically remain in service.

Appendix A.3.2   Forecast Data

The Forecast Data worksheet contains estimates of future fuel prices, which are used when calculating pre-tax fuel outlays and fuel tax revenues. It also contains the share of Ethanol-85 to Gasoline fuel, projected for each calendar year.

Table 17. Forecast Data Worksheet (sources data shown as samples)

Model Characteristic	Units	Definition/Notes	Source
Retail Fuel Prices	$/gallon	2007 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000	Average Values from AEO 2008 Early Release; Low and High Values from AEO 2007
Fuel Taxes	$/gallon	2007 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000	calculated from "Federal Fuel Tax" and "Average State Fuel Tax" components, obtained from FHWA Highway Statistics, Tables FE-21B and MF-121T
Pre-Tax Fuel Price	$/gallon	2007 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000	calculated
E85 Share	percent	percent share of Ethanol-85 vs. Gasoline fuel used during each calendar year; varies by fuel type, forecast by calendar year staring with MY-2000	

Appendix A.3.3   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. As mentioned above, the user can define and edit all inputs. For example, although Table 18 identifies available sources of information for economic values, the system does not require that the user rely on these sources.

Table 18. Economic Values Worksheet (sources data shown as samples)

Model Characteristic	Units	Definition/Notes	Source
Rebound Effect	percent	increase in the annual use of vehicle models in response to lower per-mile cost of driving a more fuel-efficient vehicle	various
Discount Rate	percent	percent rate by which the dollar value of a benefit or cost is reduced when its receipt or payment is postponed by one additional year into the future	Office of Management and Budget, office of Information and Regulatory Analysis
Payback Period	integer	number of years required for an initial investment to be repaid in the form of future benefits or cost savings	
Kf	$/mpg	the CAFE fine rate	
"Gap" between Test and On-Road MPG	percent	difference between a vehicle's EPA fuel economy rating and its actual on-road fuel economy	EPA/OTAQ estimate
Value of Travel Time per Vehicle	$/hour	amount that the driver of a vehicle would be willing to pay to reduce the time required to make a trip	Volpe estimates
Economic Costs of Oil Imports	*various*	economic costs of various oil imports	
"Monopsony" Component	$/gallon	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 demand to its world price among other participants in the international oil market	Leiby et al.
Price Shock Component	$/gallon	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	$/gallon	costs of taxpayers for maintaining a military presence to secure the supply of oil imports from potentially unstable regions of the world and protect the nation against their interruption	
Total Economic Costs ($/gallon)	$/gallon	total economic costs of oil imports (sum of monopsony, price shock, and military security components)	calculated
Total Economic Costs ($/BBL)	$/BBL	total economic costs of oil imports, specified in $/BBL	
External Costs from Additional Vehicle Use Due to "Rebound" Effect	*$/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
Congestion	$/vehicle-mile	congestion component of external costs from additional vehicle use	
Accidents	$/vehicle-mile	accidents component of external costs from additional vehicle use	
Noise	$/vehicle-mile	noise component of external costs from additional vehicle use	
Emission Damage Costs	*various*	additional costs arising from emission damage	
Carbon Monoxide	$/ton	economic costs arising from Carbon Monoxide damage	McCubbin & DeLucchi
Volatile Organic Compounds	$/ton	economic costs arising from Volatile Organic Compounds damage	
Nitrogen Oxides	$/ton	economic costs arising from Nitrous Oxides damage	OMB (1998), p. 72
Particulate Matter	$/ton	economic costs arising from Particulate Matter damage	
Sulfur Dioxide	$/ton	economic costs arising from Sulfur Oxides damage	
Annual Growth Rate for Average VMT per Vehicle	*various*	annual growth rate for average VMT per vehicle	
Base Year for Average Annual Usage Data	model year	base year for annual growth rate for average VMT per vehicle	
Cars	percent	annual growth rate for average VMT per vehicle for passenger cars	
Trucks	percent	annual growth rate for average VMT per vehicle for light trucks	
Cost of CO-2	$/metric ton	economic costs arising from Carbon Dioxide damage, by calendar year; estimates for low, average, high, or very high growth rates are provided	
CO-2 Discount Rates	percent	discount rates to apply to low, average, high, or very high Carbon Dioxide estimates	

Appendix A.3.4   Fuel Properties

The Fuel Properties worksheet contains estimates of the physical properties of gasoline, diesel, and other types of fuels, 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 calculate the 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 19. Fuel Properties Worksheet (sources data shown as samples)

Model Characteristic	Units	Definition/Notes	Source
Energy Density	BTU/gallon	amount of energy stored in a given system or region of space per unit volume, specified 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/gallon	mass per unit volume, specified by fuel type	
Carbon Content	percent by weight	average share of carbon in fuel, specified by fuel type	
SO-2 Emissions	grams/gallon	Sulfur Oxides emissions rate of gasoline and diesel fuels	
Share of Fuel Savings Leading to Lower Fuel Imports	percent	assumed value for share of fuel savings leading to lower fuel imports	Energy Information Administration, Annual Energy Outlook 2003, Tables 1, 2, and 117; and Volpe assumptions
Share of Fuel Savings Leading to Reduced Domestic Fuel Refining	percent	assumed value for share of fuel savings leading to reduced domestic fuel refining	
Share of Reduced Domestic Refining from Domestic Crude	percent	assumed value for share of reduced domestic refining from domestic crude	
Share of Reduced Domestic Refining from Imported Crude	percent	assumed value for share of reduced domestic refining from imported crude	
Assumed Gasoline 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

Appendix A.3.5   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.

Table 20. Upstream Emissions Worksheet (sources data shown as samples)

Model Characteristic	Units	Definition/Notes	Source
Petroleum Extraction	grams/mil BTU	total emissions by stage of fuel production and distribution from petroleum extraction, specified 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
Petroleum Transportation	grams/mil BTU	total emissions by stage of fuel production and distribution from petroleum transportation, specified by pollutant and fuel type	
Petroleum Refining	grams/mil BTU	total emissions by stage of fuel production and distribution from petroleum refining, specified by pollutant and fuel type	
Fuel TS&D	grams/mil BTU	total emissions by stage of fuel production and distribution from refined fuel transportation, storage, and delivery, specified by pollutant and fuel type	

Appendix A.3.6   Monte-Carlo

The Monte-Carlo worksheet contains parameters for setting up pseudo-random trial for uncertainty analysis.

Table 21. Monte-Carlo Worksheet

Monte-Carlo	Discount Rates (%)	percent	comma-separated list of discount rates to use during Monte-Carlo modeling
	Fuel Path Randomization Parameters	percent	randomization parameters for the low, reference, or high fuel path
	Rebound Effect Randomization Parameters		parameters for generating randomized rebound effect values
	Carbon Dioxide Randomization Parameters	percent	randomization parameters for the low, average, high or very high Carbon Dioxide path
	Monopsony Randomization Parameters	dollars	parameters for generating randomized monopsony cost values
	Price Shock Randomization Parameters	dollars	parameters for generating randomized price shock cost values
	Military Security Randomization Parameters	dollars, percent	parameters for generating randomized military security cost values

Appendix A.4   Emissions Rates File

The emissions rates file contains vehicular criteria pollutant emission factors. Emission factors (all in grams per mile and specific to both vehicle model year and age) for all fuel types (gasoline, reformulated gasoline, and Diesel, E85, CFG, Hydrogen, and two spares) and five pollutants (CO, VOC, NO_X, $PM_{2.5}$, and SO_2) are contained in a series of forty worksheets of identical structure. Some of the fuel types specified are provided for future use, and may not have been part of the current analysis.

Table 22. Emissions Rates Worksheet (shown for CO - Gasoline only) (sources data shown as samples)

Model Characteristic	Units	Definition/Notes	Source
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.	

Covered pollutants include carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NOX), sulfur dioxide (SO2), and fine particulate matter (PM2.5, 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), 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.

Appendix A.5   Scenarios File

The scenarios file provides one or more worksheets that begin with "SCEN_" and 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 as 0, 1, 2 …, based on their order of appearance. The first worksheet is assigned to Scenario 0, and 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 23. Regulatory Classes

Reg. Class	Includes
0	Unregulated vehicles
1	Passenger automobiles (domestic)
2	Passenger automobiles (imported)
3	Nonpassenger automobiles

The "Regulatory Class" column on the vehicles worksheet discussed above is used to indicate whether the vehicle is regulated as a passenger or nonpassenger automobile. The vehicle origin is further used to differentiate between regulatory classes 1 and 2 (domestic or imported). Vehicles from one regulatory class may also be reassigned into another via the Regulatory Declassification section of the scenario as shown in Table 24.

Table 24. Regulatory Declassification Codes

Code	Description
<blank>	Specifies that regulatory merging does not apply.
RC1	Specifies that all passenger automobiles (domestic and imported) should be merged into regulatory class 1.
RC3	Specifies that all vehicles should be merged into regulatory class 3.

Table 25 shows an example of a CAFE scenario definition worksheet.

Table 25. Scenario Definition Worksheet (Sample)

CAFE Scenario Definition		Model Year							
Scenario Description		MY2011 standards							
Regulatory Declassification		2010	2011	2012	2013	2014	2015	2016	2017
			RC1	RC1	RC1	RC1	RC1	RC1	
		2010	2011	2012	2013	2014	2015	2016	2017
	Fnc Type		2	2	2	2	2	2	
	Coefficients								
	A		31.2	31.2	31.2	31.2	31.2	31.2	
Passenger Automobile Standards	B		24.0	24.0	24.0	24.0	24.0	24.0	
	C		51.4	51.4	51.4	51.4	51.4	51.4	
	D		1.9	1.9	1.9	1.9	1.9	1.9	
	Alt. Minimum								
	mpg		27.5	27.5	27.5	27.5	27.5	27.5	
	% average		92%	92%	92%	92%	92%	92%	
		2010	2011	2012	2013	2014	2015	2016	2017
	Fnc Type		2	2	2	2	2	2	
	Coefficients								
	A		27.1	27.1	27.1	27.1	27.1	27.1	
Nonpassenger Automobile Standards	B		21.1	21.1	21.1	21.1	21.1	21.1	
	C		56.4	56.4	56.4	56.4	56.4	56.4	
	D		4.3	4.3	4.3	4.3	4.3	4.3	
	Alt. Minimum								
	mpg								
	% average								
Comply By Industry		2010	2011	2012	2013	2014	2015	2016	2017
Annual CAFE Growth Rate for EIS Modeling									
Passenger	Up to 2020	0.00%							
	After 2020	0.00%							
Nonpassenger	Up to 2020	0.00%							
	After 2020	0.00%							

The purpose of each of the defined sections is as follows:

- *Scenario Description*: A short name describing the key features of the scenario.

- *Regulatory Declassification*: Specifies whether vehicles from one regulatory class should be merged with vehicles from another regulatory class.

- *Passenger Automobile Standards*: The CAFE functional or flat standards to use during modeling of the scenario. The "Fnc Type" subsection determines the functional form the system will use for the specific scenario. Presently, the supported functional forms are: 1, for flat standards; 2 for a logistic area-based functional form; and 6, for a linear area-based functional form. The "Coefficients" subsection contains corresponding coefficient values. And the "Alt. Minimum" sub-section applies to non-flat standard scenarios and represents the alternative minimum CAFE standards to apply to manufacturers whose required functional CAFE standard is below a specific minimum (mpg), or less than the specific percentage of the industry average (% average). In the example scenario in Table 25, function type "2" is used, indicating that passenger automobiles should use a logistic area-based functional form, with the coefficients specified in fields A through D.

- ***Nonpassenger Automobile Standards***: Same as the Passenger Automobile Standards section above, but applies to nonpassenger automobiles.

- ***Comply By Industry***: "Y" forces the model to treat the entire industry as one manufacturer and perform compliance simulation on all manufacturers at the same time; "N" or blank is the default and performs compliance simulation on each manufacturer individually.

- ***Annual CAFE Growth Rate for EIS Modeling***: This section applies only when the modeling system is used to perform supplemental analysis necessary for the Environmental Impact Statement. It specifies the rate at which to growth the achieved CAFE levels past the last analysis year.

Appendix A.6   EIS Parameters File

The EIS parameters file contains additional modeling parameters required to perform supplemental analysis necessary for the Environmental Impact Statement (EIS). The file contains a series of worksheets, the contents of which are summarized below.

Appendix A.6.1   Parameters

The Parameters worksheet contains base parameters for use in EIS analysis.

Table 26. Parameters Worksheet (Sample)

Annual Growth Rate for Average VMT per Vehicle	
Base Year for Average Annual Usage Data	2001
Cars	1.15%
Light Trucks	1.15%
Rebound Effect	10%
On-Road Fuel Economy Gap	20%
Elasticity of Vehicle Use wrt Fuel Price per Gallon (SR)	-0.10

Appendix A.6.2   Emissions Rates

The Emissions Rates worksheet contains upstream emission factors, specified in grams per gallon, for greenhouse gases (CO_2, CH_4, and N_2O), criteria pollutants (VOC, CO, NOx, PM2.5, and SOx), and air toxics (formaldehyde, acetaldehyde, butadiene, benzene, acrolein, MTBE, and diesel PM). This worksheet also contains tailpipe emissions, in grams per gallon, for selected pollutants (CO_2 and SOx). The rest of the tailpipe emissions are provided in the EIS Tailpipe Emissions file.

Table 27. Emissions Rates Worksheet (Sample)

Upstream Emission Rates (grams per gallon)

	Greenhouse Gases			Criteria Pollutants					Air Toxics						
	CO2	CH4	N2O	VOC	CO	NOx	PM2.5	SOx	Formaldehyde	Acetaldehyde	Butadiene	Benzene	Acrolein	MTBE	Diesel PM
Gasoline	2,072	12.5191	0.1011	5.1451	0.4921	1.5405	0.2097	0.9419	0.00412	0.00055	0.00012	0.01113	0.00008	0.00000	0.58700
Diesel	2,105	13.5817	0.0334	0.5992	0.9289	2.7099	0.4068	1.8534	0.00482	0.00061	0.00026	0.00476	0.00009	0.00000	0.47327

Tailpipe Emission Rates (grams per gallon)

	CO2	SOx
Gasoline	8,852	0.170
Diesel	10,239	0.096

Appendix A.6.3   Upstream Process Emission Rates

The Upstream worksheet contains emission factors by stage of processing for criteria pollutants and air toxics. The emission factors are separated, for each pollutant, by fuel type and stage of fuel production (petroleum extraction, petroleum transportation, petroleum refining, and fuel TS&D). This worksheet performs internal calculations to

obtain the domestic emissions by stage of fuel production and distribution, specified in grams per gallon, as shown in the table below.

Table 28. Upstream Worksheet (Excerpt, shown for selected pollutants)

Pollutant	Fuel Type	Domestic Emissions by Stage of Fuel Production and Distribution (grams/gallon)				
		Petroleum Extraction	Petroleum Transportation	Petroleum Refining	Fuel TS&D	Total
CO	Conventional Gasoline	0.0176	0.0109	0.3787	0.0869	**0.4941**
	Federal Reformulated Gasoline	0.0173	0.0106	0.3732	0.0872	**0.4883**
	California Reformulated Gasoline	0.0214	0.0066	0.3743	0.0875	**0.4897**
	Weighted Average for Gasoline	0.0175	0.0108	0.3768	0.0870	**0.4921**
	Low Sulfur Diesel	0.0393	0.0242	0.7644	0.1010	**0.9289**
VOC	Conventional Gasoline	0.0074	0.0102	0.1835	4.9817	**5.1828**
	Federal Reformulated Gasoline	0.0072	0.0100	0.1824	4.8755	**5.0751**
	California Reformulated Gasoline	0.0074	0.0099	0.1829	4.8894	**5.0896**
	Weighted Average for Gasoline	0.0073	0.0102	0.1831	4.9445	**5.1451**
	Low Sulfur Diesel	0.0165	0.0228	0.3966	0.1633	**0.5992**
NOx	Conventional Gasoline	0.0419	0.0446	1.0315	0.4284	**1.5465**
	Federal Reformulated Gasoline	0.0410	0.0437	1.0146	0.4301	**1.5294**
	California Reformulated Gasoline	0.0532	0.0318	1.0175	0.4313	**1.5338**
	Weighted Average for Gasoline	0.0416	0.0443	1.0256	0.4290	**1.5405**
	Low Sulfur Diesel	0.0935	0.0996	2.0545	0.4623	**2.7099**

Appendix A.6.4   Fuel Prices

The Fuel Prices worksheet provides historical and forecast retail fuel prices, specified 2007$ per gallon. Historical data is provided between 1975 and 2005; forecast data is between 2006 and 2060.

Table 29. Fuel Prices Worksheet (Sample)

Calendar Year	Gasoline			Diesel		
	Low	Reference	High	Low	Reference	High
1975	$1.788	$1.788	$1.788	$1.788	$1.788	$1.788
1976	$1.759	$1.759	$1.759	$1.759	$1.759	$1.759
...						
2000	$1.873	$1.873	$1.873	$1.787	$1.787	$1.787
2001	$1.791	$1.791	$1.791	$1.639	$1.639	$1.639
2002	$1.657	$1.657	$1.657	$1.517	$1.517	$1.517
2003	$1.844	$1.844	$1.844	$1.699	$1.699	$1.699
2004	$2.105	$2.105	$2.105	$1.981	$1.981	$1.981
2005	$2.478	$2.478	$2.478	$2.546	$2.546	$2.546
2006	$2.707	$2.707	$2.707	$2.786	$2.786	$2.786
2007	$2.822	$2.831	$2.822	$2.870	$2.894	$2.870
2008	$3.205	$3.172	$3.205	$3.723	$3.714	$3.723
2009	$2.282	$2.279	$2.282	$2.630	$2.387	$2.630
2010	$2.213	$2.441	$3.078	$2.278	$2.566	$3.020
2011	$2.194	$2.473	$3.361	$2.251	$2.591	$3.387
2012	$2.103	$2.609	$3.627	$2.164	$2.752	$3.701
2013	$2.082	$2.844	$3.914	$2.163	$2.889	$4.042
2014	$2.044	$2.954	$4.241	$2.191	$2.984	$4.410
2015	$2.028	$3.004	$4.496	$2.161	$3.077	$4.671
2016	$2.033	$3.072	$4.656	$2.162	$3.176	$4.818
2017	$2.035	$3.135	$4.838	$2.160	$3.254	$4.995
2018	$2.041	$3.185	$4.935	$2.169	$3.342	$5.097
2019	$2.025	$3.222	$5.003	$2.146	$3.393	$5.154
2020	$2.024	$3.268	$5.043	$2.147	$3.434	$5.201
...						
2059	$2.070	$4.934	$6.933	$2.278	$5.170	$6.819
2060	$2.071	$4.987	$6.990	$2.282	$5.225	$6.866

Appendix A.6.5   Forecast Data

The Forecast Data worksheet contains age-specific estimates of the survival rate and annual accumulated mileage applicable to passenger cars and light trucks. Original and "conditional" survival rates are provided, both of which are used internally in the worksheet. The former are used for adjusting the conditional rates, while the latter are used to estimate data in the Car Fleet and Truck Fleet worksheets. The accumulated millage section provides three separate paths (for each vehicle type) for miles driven at low, reference, and high fuel prices.

Table 30. Forecast Data Worksheet (Sample)

Vehicle Age	Original Survival Rates		Conditional Survival Rates		Average Annual Miles Driven					
	Passenger Cars	Light Trucks	Passenger Cars	Light Trucks	Passenger Cars			Light Trucks		
					Low	Reference	High	Low	Reference	High
0	100.00%	100.00%	100.00%	100.00%	14,231	14,231	14,231	16,085	16,085	16,085
1	99.50%	99.50%	99.50%	99.50%	13,961	13,961	13,961	15,782	15,782	15,782
2	99.00%	97.41%	99.50%	97.90%	13,669	13,669	13,669	15,442	15,442	15,442
3	98.31%	96.03%	99.30%	98.58%	13,357	13,357	13,357	15,069	15,069	15,069
4	97.31%	94.20%	98.98%	98.09%	13,028	13,028	13,028	14,667	14,667	14,667
5	95.93%	91.90%	98.58%	97.56%	12,683	12,683	12,683	14,239	14,239	14,239
6	94.13%	89.13%	98.12%	96.99%	12,325	12,325	12,325	13,790	13,790	13,790
7	91.88%	85.90%	97.61%	96.38%	11,956	11,956	11,956	13,323	13,323	13,323
8	89.18%	82.26%	97.06%	95.76%	11,578	11,578	11,578	12,844	12,844	12,844
9	86.04%	78.27%	96.48%	95.15%	11,193	11,193	11,193	12,356	12,356	12,356
10	82.52%	74.01%	95.91%	94.56%	10,804	10,804	10,804	11,863	11,863	11,863
11	78.66%	69.56%	95.32%	93.99%	10,413	10,413	10,413	11,369	11,369	11,369
12	71.70%	65.01%	91.15%	93.46%	10,022	10,022	10,022	10,879	10,879	10,879
13	61.25%	60.42%	85.43%	92.94%	9,633	9,633	9,633	10,396	10,396	10,396
14	50.94%	55.17%	83.17%	91.31%	9,249	9,249	9,249	9,924	9,924	9,924
15	41.42%	50.09%	81.31%	90.79%	8,871	8,871	8,871	9,468	9,468	9,468
16	33.08%	45.22%	79.86%	90.28%	8,502	8,502	8,502	9,032	9,032	9,032
17	26.04%	40.62%	78.72%	89.83%	8,144	8,144	8,144	8,619	8,619	8,619
18	20.28%	36.33%	77.88%	89.44%	7,799	7,799	7,799	8,234	8,234	8,234
19	15.65%	32.36%	77.17%	89.07%	7,469	7,469	7,469	7,881	7,881	7,881
20	12.00%	28.73%	76.68%	88.78%	7,157	7,157	7,157	7,565	7,565	7,565
21	9.16%	25.42%	76.33%	88.48%	6,866	6,866	6,866	7,288	7,288	7,288
22	6.96%	22.44%	75.98%	88.28%	6,596	6,596	6,596	7,055	7,055	7,055
23	5.27%	19.75%	75.72%	88.01%	6,350	6,350	6,350	6,871	6,871	6,871
24	3.99%	17.35%	75.71%	87.85%	6,131	6,131	6,131	6,739	6,739	6,739
25	3.01%	15.22%	75.44%	87.72%	5,940	5,940	5,940	6,663	6,663	6,663
26	2.27%	13.32%	75.42%	87.52%	5,780	5,780	5,780	6,648	6,648	6,648
27	0.00%	11.65%	0.00%	87.46%	5,654	5,654	5,654	6,648	6,648	6,648
28	0.00%	10.17%	0.00%	87.30%	5,562	5,562	5,562	6,648	6,648	6,648
29	0.00%	8.87%	0.00%	87.22%	5,508	5,508	5,508	6,648	6,648	6,648
30	0.00%	7.73%	0.00%	87.15%	5,508	5,508	5,508	6,648	6,648	6,648
31	0.00%	6.73%	0.00%	87.06%	5,508	5,508	5,508	6,648	6,648	6,648
32	0.00%	5.86%	0.00%	87.07%	5,508	5,508	5,508	6,648	6,648	6,648
33	0.00%	5.09%	0.00%	86.86%	5,508	5,508	5,508	6,648	6,648	6,648
34	0.00%	4.43%	0.00%	87.03%	5,508	5,508	5,508	6,648	6,648	6,648
35	0.00%	3.85%	0.00%	86.91%	5,508	5,508	5,508	6,648	6,648	6,648
36	0.00%	3.34%	0.00%	86.75%	5,508	5,508	5,508	6,648	6,648	6,648
37	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
38	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
39	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
40	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
41	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
42	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
43	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
44	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
45	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
46	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
47	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
48	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
49	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
50	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
51	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
52	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
53	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
54	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
55	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
56	0.00%	0.00%	100.00%	100.00%	5,508	5,508	5,508	6,648	6,648	6,648
57	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
58	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
59	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648
60	0.00%	0.00%	0.00%	0.00%	5,508	5,508	5,508	6,648	6,648	6,648

Appendix A.6.6   Sales, Car Fleet, and Truck Fleet

The Sales worksheet contains projected vehicle production for sale in the U.S. between model years 2005 and 2060. The Sales worksheet is used internally to estimate data that goes into the Car Fleet and Truck Fleet worksheets.

Table 31. Sales Worksheet (Sample)

Calendar Year	Passenger Cars	Light Trucks	Total
2005	7,698,885	8,125,438	15,824,323
2006	7,809,903	7,875,145	15,685,047
2007	7,704,630	7,474,079	15,178,708
2008	6,614,097	5,830,264	12,444,360
2009	4,829,454	4,383,431	9,212,885
2010	5,136,304	5,270,257	10,406,561
2011	7,922,670	5,457,537	13,380,207
2012	9,122,736	5,798,295	14,921,031
2013	9,797,100	6,038,091	15,835,190
2014	10,231,299	5,947,426	16,178,725
2015	10,626,436	5,826,239	16,452,676
2016	10,831,738	5,669,364	16,501,102
2017	10,694,688	5,490,255	16,184,943
2018	10,688,660	5,281,916	15,970,576
2019	10,930,975	5,191,409	16,122,384
2020	11,387,039	5,154,528	16,541,566
...			
2059	17,083,605	6,370,273	23,453,879
2060	17,235,456	6,426,897	23,662,353

The Car Fleet and Truck Fleet worksheets provide historic and projected data of vehicles remaining on the road, specified by model year and calendar year. The period of years covered is between 1975 and 2060. The conditional survival rates on the Forecast Data worksheet, along with forecast of sales on the Sales worksheet are used when estimating the projected data.

Table 32. Car Fleet (Sample)

Model Year	Calendar Year										
	1975	1976	1977	1978	1979	1980	1981	1982	...	2059	2060
1975	5,155,795	7,459,274	7,395,419	7,206,478	6,911,003	6,608,778	6,391,110	6,120,707		0	0
1976		6,533,377	9,452,325	9,371,408	9,096,899	8,797,199	8,632,878	8,371,761		0	0
1977			7,096,747	10,267,394	10,110,566	9,823,405	9,649,940	9,552,440		0	0
1978				7,358,777	10,573,362	10,358,469	10,165,079	10,029,281		0	0
1979					7,207,394	10,277,491	10,119,116	9,950,999		0	0
1980						5,806,894	8,707,110	8,712,739		0	0
1981							5,064,756	8,127,671		0	0
1982								4,326,717		0	0
...											
2059										13,169,445	16,925,159
2060										826,571	13,286,504

The structure of both worksheets (Car Fleet and Truck Fleet) is identical.

Appendix A.6.7 Fuel Economy

The Fuel Economy worksheet contains actual fuel economy levels and diesel shares covering the years between 1975 and 2060. Data is provided for gasoline and diesel fuel types and is separated by passenger cars and light trucks. The data is further separated into two subsections, one working under the assumption that the CAFE program does not exists ("Without CAFE"), and the other taking the impact of the CAFE program into account ("With CAFE").

For the "Without CAFE" subsection, the fuel economy levels and diesel shares are flatlined after 1977, all the way to 2060. In the "With CAFE" subsection, historic data is provided up to 2010. For model years 2011 to 2016, resultant fuel economy levels and diesel shares form the modeling analysis are inserted in place of historic data. Data in model years 2017 to 2060 are either flatlined, based on the 2016 values, or incremented by the growth rates specified in the scenarios file, depending on the assumptions used during EIS modeling.

Table 33. Fuel Economy Worksheet (Sample)

| Model Year | Passenger Cars | | | | | | Light Trucks | | | | | |
| | Without CAFE | | | With CAFE | | | Without CAFE | | | With CAFE | | |
	Gasoline	Diesel	Diesel Share	Gasoline	Diesel	Diesel Share	Gasoline	Diesel	Diesel Share	Gasoline	Diesel	Diesel Share
1975	15.8	15.8	0.3%	15.8	15.8	0.3%	13.7	13.7	0.3%	13.7	13.7	0.3%
1976	17.5	17.5	1.1%	17.5	17.5	1.1%	14.4	14.4	0.3%	14.4	14.4	0.3%
...												
2000	18.3	18.3	1.9%	28.5	28.5	0.3%	15.2	15.2	0.3%	21.3	21.3	0.3%
2001	18.3	18.3	1.9%	28.8	28.8	0.2%	15.2	15.2	0.3%	20.9	20.9	0.3%
2002	18.3	18.3	1.9%	29.0	29.0	0.4%	15.2	15.2	0.3%	21.4	21.4	0.3%
2003	18.3	18.3	1.9%	29.5	29.5	0.5%	15.2	15.2	0.3%	21.8	21.8	0.3%
2004	18.3	18.3	1.9%	29.5	29.5	0.4%	15.2	15.2	0.3%	21.5	21.5	0.3%
2005	18.3	18.3	1.9%	30.3	30.3	0.6%	15.2	15.2	0.3%	22.1	22.1	0.3%
2006	18.3	18.3	1.9%	29.9	29.9	0.6%	15.2	15.2	0.3%	22.5	22.5	0.3%
2007	18.3	18.3	1.9%	30.0	30.0	0.6%	15.2	15.2	0.3%	22.5	22.5	0.4%
2008	18.3	18.3	1.9%	30.1	30.1	0.6%	15.2	15.2	0.3%	22.5	22.5	0.6%
2009	18.3	18.3	1.9%	30.3	30.3	0.6%	15.2	15.2	0.3%	22.6	22.6	0.8%
2010	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2011	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2012	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2013	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2014	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2015	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2016	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2017	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2018	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2019	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2020	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
...												
2059	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%
2060	18.3	18.3	1.9%	30.4	30.4	0.6%	15.2	15.2	0.3%	22.6	22.6	1.0%

Appendix A.7   EIS Tailpipe Emissions

The EIS tailpipe emissions file contains pollutant emission factors necessary for EIS analysis. Emission factors are specified in grams per mile by calendar and model years, covering the period between 1975 and 2060. The included pollutants are: acetaldehyde, acrolein, benzene, butadiene, CH4, CO, diesel PM10, formaldehyde, MTBE, N2O, NOx, PM, SO2, and VOC. Each pollutant contains emissions factors separated by gasoline and diesel fuel types, as well as by cars and trucks (LDGV for gasoline cars, LDGT for gasoline trucks, LDDV for diesel cars, and LDDT for diesel trucks).

Table 34. EIS Tailpipe Emissions (Sample for sellected pollutant & fuel type only)

Model Year	Calendar Year										
	1975	1976	1977	1978	1979	1980	1981	1982	…	2059	2060
1975	0.01700	0.02202	0.02761	0.03302	0.03831	0.04351	0.04102	0.04209		0.09408	0.09408
1976		0.01700	0.02202	0.02761	0.03302	0.03831	0.04351	0.04102		0.09408	0.09408
1977			0.01700	0.02202	0.02761	0.03302	0.03831	0.04351		0.09408	0.09408
1978				0.01686	0.02182	0.02735	0.03270	0.03793		0.09271	0.09271
1979					0.01683	0.02179	0.02732	0.03266		0.09256	0.09256
1980						0.00733	0.01148	0.01621		0.06457	0.06457
1981							0.00553	0.00765		0.03059	0.03059
1982								0.00538		0.02798	0.02798
…											
2059										0.00046	0.00047
2060											0.00046

Appendix B   Model Outputs

The system produces seven formatted output files, all as Microsoft Excel workbooks, four of which are for each scenario defined in the compliance model scenarios file, two cumulative output files covering all scenarios, and one output file applicable only when performing optimization modeling. The system places all files in the "reports" folder, located in the user selected output path (ex: **C:\cafe\demo-run\demo\reports**).   Table 35 lists the available output files and their contents. As discussed earlier, the first scenario appearing in the scenarios 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.[20]

Table 35. Output Files

Output File[21]	Contents
Industry_Report_Sn*.xls	Contains industry-wide and manufacturer-specific results, showing all model years per worksheet, for each regulatory class:[22] sales; preliminary and final value of CAFE standard; 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.
Manufacturers_Report_Sn*.xls	Contains industry-wide and manufacturer-specific results, showing one model year per worksheet, for each regulatory class: sales; preliminary and final value of CAFE standard; 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_Report_Sn*.xls	Provides vehicle model-specific results: index, ID number, manufacturer, model name, nameplate, regulatory class, technology class, predecessor ID number, 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, redesign and refresh states, application and usage status of each technology.
ScenSummary_Report.xls	Displays a summary of industry-wide and manufacturer-specific results, compared versus the baseline for all scenarios: total costs and benefits (manufacturer and total cost, fuel savings, preliminary and final value of CAFE standard, total and net benefits, and benefit-to-cost ratio); price increase.
Effects_Report_Sn*.xls	Provides national-scale effects: travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions, and economic externalities related to highway travel and petroleum consumption.
EA_Report.xls	Presents national-scale effects, for all scenarios, disaggregated by calendar year for each model year: fuel consumption and carbon dioxide and criteria pollutant

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[20] For example, if the baseline scenario involves a flat 27.5 mpg standard for passenger automobiles and Scenario 3 examines a reformed standard with a higher average required value of CAFE standard, Industry_Summary_Sn3.xls might report total technology costs of $2.2b, of which about $2.0b might be attributable to the increase in the overall standard.

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

[22] As discussed earlier, RC0=unregulated vehicles, RC1=domestic passenger autos, RC2=imported passenger autos, and RC3 =nonpassenger autos (i.e., light trucks).

	emissions.
OptIndExt_Report.xls	Provides industry-wide and manufacturer-specific technology costs, fines, and benefits, as well as carbon dioxide and fuel savings, and benefit-cost ratios, for all iterations from industry optimization. This report also graphs the socially optimized functional form (aka, optimized shape) for the entire industry by model year, and displays benefit-cost, marginal benefit:cost, net benefits, and optimized shape charts.

The remainder of this section shows sample output files for a scenario based on reformed passenger automobile standards. This scenario addresses model years spawning six years (2011-2016), however, only years 2012 and 2016 are displayed in most screenshots. The scenario assumes regulatory merging of all vehicles into RC1 (domestic passenger autos). Also, because the output files produced by the system are extensive, the text shows only portions of some files. Furthermore, although the system produces output specific to each represented vehicle model, only the more summarized output files are shown here.

Appendix B.1   Industry Report

Table 36. Industry Report (Sample)

Industry Overall		2012 Total			2016 Total		
		Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Total Sales	Unregulated	0	0	- %	0	0	- %
	Dom Auto	9,122,736	0	- %	10,831,738	0	- %
	Imp Auto	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %
	Overall	9,122,736	0	- %	10,831,738	0	- %
Value of Preliminary CAFE Standard	Unregulated	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	33.35	2.86	9%	37.76	7.28	24%
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %
	Overall	33.35	2.86	9%	37.76	7.28	24%
Value of Final CAFE Standard	Unregulated	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	33.35	2.86	9%	37.76	7.28	24%
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %
	Overall	33.35	2.86	9%	37.76	7.28	24%
Average Fuel Economy	Unregulated	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	32.77	1.20	4%	37.21	5.35	17%
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %
	Overall	32.77	1.20	4%	37.21	5.35	17%
Average Curb Weight (lb.)	Unregulated	0	0	- %	0	0	- %
	Dom Auto	3,281	-9	(0%)	3,177	-99	(3%)
	Imp Auto	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %
	Overall	3,281	-9	(0%)	3,177	-99	(3%)
Average Area (sq. ft.)	Unregulated	0	0	- %	0	0	- %
	Dom Auto	45	0	- %	45	0	- %
	Imp Auto	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %
	Overall	45	0	- %	45	0	- %
Average Technology Costs (RPE)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 542.23	$ 454.74	520%	$ 972.32	$ 880.22	956%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 542.23	$ 454.74	520%	$ 972.32	$ 880.22	956%
Average Fines Incurred (RPE)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 53.65	$ 49.80	1293%	$ 27.18	$ 26.84	7935%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 53.65	$ 49.80	1293%	$ 27.18	$ 26.84	7935%
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 595.88	$ 504.54	552%	$ 999.49	$ 907.06	981%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 595.88	$ 504.54	552%	$ 999.49	$ 907.06	981%
Total Incurred Technology Costs ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$4,946.65	$4,148.47	520%	$10,531.86	$9,534.29	956%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$4,946.65	$4,148.47	520%	$10,531.86	$9,534.29	956%
Total Fines Owed ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 489.40	$ 454.28	1293%	$ 294.39	$ 290.72	7935%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 489.40	$ 454.28	1293%	$ 294.39	$ 290.72	7935%
Total Increase in Sales Revenue ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$5,436.05	$4,602.75	552%	$10,826.25	$9,825.01	981%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$5,436.05	$4,602.75	552%	$10,826.25	$9,825.01	981%

Appendix B.2   Manufacturers Report

Table 37. Manufacturers Report (Sample)

Manufacturer		MFR-1 Current Scenario	MFR-1 Delta (abs.)	MFR-1 Delta (%)	MFR-2 Current Scenario	MFR-2 Delta (abs.)	MFR-2 Delta (%)	MFR-3 Current Scenario	MFR-3 Delta (abs.)	MFR-3 Delta (%)
Total Sales	Unregulated	0	0	- %	0	0	- %	0	0	- %
	Dom Auto	326,314	0	- %	1,355,584	0	- %	388,130	0	- %
	Imp Auto	0	0	- %	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %	0	0	- %
	Overall	326,314	0	- %	1,355,584	0	- %	388,130	0	- %
Value of Preliminary CAFE Standard	Unregulated	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	29.40	0.00	- %	30.80	0.00	- %	30.80	0.00	- %
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Overall	29.40	0.00	- %	30.80	0.00	- %	30.80	0.00	- %
Value of Final CAFE Standard	Unregulated	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	29.40	0.00	- %	30.80	0.00	- %	30.80	0.00	- %
	Imp Auto	0.00	0.00	- %	0.00	0.00	%	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	%	0.00	0.00	- %
	Overall	29.40	0.00	- %	30.80	0.00	- %	30.80	0.00	- %
Average Fuel Economy	Unregulated	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	28.16	0.00	- %	35.11	0.00	- %	30.48	0.00	- %
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %	0.00	0.00	- %
	Overall	28.16	0.00	- %	35.11	0.00	- %	30.48	0.00	- %
Average Curb Weight (lb.)	Unregulated	0	0	- %	0	0	- %	0	0	- %
	Dom Auto	3,572	0	- %	3,109	0	- %	3,445	0	- %
	Imp Auto	0	0	- %	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %	0	0	- %
	Overall	3,572	0	- %	3,109	0	- %	3,445	0	- %
Average Area (sq. ft.)	Unregulated	0	0	- %	0	0	- %	0	0	- %
	Dom Auto	47	0	- %	44	0	- %	44	0	- %
	Imp Auto	0	0	- %	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %	0	0	- %
	Overall	47	0	- %	44	0	- %	44	0	- %
Average Technology Costs (RPE)	Unregulated	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 22.07	$ -	- %	$ -	$ -	- %	$ 171.67	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 22.07	$ -	- %	$ -	$ -	- %	$ 171.67	$ -	- %
Average Fines Incurred (RPE)	Unregulated	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ -	$ -	- %	$ -	$ -	- %	$ 16.50	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ -	$ -	- %	$ -	$ -	- %	$ 16.50	$ -	- %
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	Unregulated	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 22.07	$ -	- %	$ -	$ -	- %	$ 188.17	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 22.07	$ -	- %	$ -	$ -	- %	$ 188.17	$ -	- %
Total Incurred Technology Costs ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 7.20	$ -	- %	$ -	$ -	- %	$ 66.63	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 7.20	$ -	- %	$ -	$ -	- %	$ 66.63	$ -	- %
Total Fines Owed ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ -	$ -	- %	$ -	$ -	- %	$ 6.40	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ -	$ -	- %	$ -	$ -	- %	$ 6.40	$ -	- %
Total Increase in Sales Revenue ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 7.20	$ -	- %	$ -	$ -	- %	$ 73.04	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 7.20	$ -	- %	$ -	$ -	- %	$ 73.04	$ -	- %

Appendix B.3 Vehicles Report

Table 38. Vehicles Report (Contents)

Group	Column	Contents
Index		Unique vehicle index across the entire industry.
ID#		Unique vehicle ID per manufacturer.
Manufacturer		The manufacturer of the vehicle.
Model		Name of the vehicle model.
Name Plate		The nameplate of the vehicle.
Reg Class		The regulatory class assignment of the vehicle.
Technology Class		The technology class of the vehicle.
Pred ID#		ID number of the vehicle's predecessor.
Total Sales	Initial	Initial sales volume (units).
	Final	Final sales volume (units).
Initial MSRP ($)		Initial MSRP ($).
Initial Price ($)		Intial Price ($).
Fuel Econ. (mpg)	Initial	Initial fuel economy.
	Final	Final fuel economy.
Curb Weight (lb)	Initial	Initial curb weight.
	Final	Final curb weight.
Area (sf)		Vehicle footprint.
Engine	ID#	ID number of the vehicle's engine.
	Fuel	Engine fuel type.
	Disp (lit.)	Engine displacement.
	Cyl.	Number of cylinders in an engine.
Transmission	ID#	ID number of the vehicle's transmission.
	Type	Type of the transmission.
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).
Redesign State		Redesign state of the vehicle.
Refresh State		Refresh state of the vehicle.
Technology Utilization/Applicability		Usage of each technology by the vehicle.

Appendix B.4   Scenario Summary Report

Table 39. Scenario Summary Report (Sample)

Total Costs ($M) and Benefits														
Manufacturer	Product Plans (Do-Nothing Standard)							Preferred Alternative						
	2011	2012	2013	2014	2015	2016	Total	2011	2012	2013	2014	2015	2016	Total
MFR-1	0	-21	-32	-25	-23	-24	-125	0	3	-2	-2	-2	-2	-4
MFR-2	0	0	0	0	0	0	0	0	157	216	302	353	388	1,416
MFR-3	-7	-34	-32	-30	-28	-28	-160	0	300	445	465	498	543	2,251
MFR-4	-67	-74	-83	-84	-89	-89	-485	0	63	213	247	279	456	1,259
MFR-5	-42	-127	-126	-181	-196	-196	-868	0	1	1	9	76	247	334
MFR-6	0	0	0	0	0	0	0	0	210	234	304	380	434	1,562
MFR-7	-1	-39	-36	-37	-41	-40	-193	0	54	57	182	284	282	858
MFR-8	-16	-22	-20	-16	-14	-14	-100	0	59	48	140	154	151	553
MFR-9	0	0	0	0	0	0	0	0	33	47	76	127	152	434
MFR-10	-64	-279	-267	-248	-258	-255	-1,371	0	710	1,384	1,637	1,937	2,004	7,672
MFR-11	-4	-9	-37	-37	-47	-47	-180	0	4	5	9	20	46	84
MFR-12	-41	-135	-135	-138	-157	-152	-758	0	2,377	2,283	2,403	2,642	2,937	12,642
MFR-13	0	0	0	0	0	0	0	0	98	269	604	669	787	2,427
MFR-14	-1	-1	-4	-4	-4	-4	-18	0	0	51	71	80	104	305
MFR-15	0	0	0	0	0	0	0	0	50	57	85	263	279	735
MFR-16	0	0	0	0	0	0	0	0	30	104	223	250	424	1,031
MFR-17	-42	-57	-70	-139	-150	-150	-609	0	0	0	100	211	301	612
Big-17 Summary														
Total	-283	-798	-842	-939	-1,007	-998	-4,867	0	4,148	5,411	6,855	8,221	9,534	34,170
Fuel Savings (BG)	-0.808	-2.126	-2.262	-2.496	-2.756	-2.830	-13.277	0.000	2.396	5.153	7.233	9.446	11.433	35.660
Preliminary Standard (MPG)	1.0	1.0	1.0	1.0	1.0	1.0		30.4	33.3	34.2	34.9	36.2	37.8	
Final Standard (MPG)	1.0	1.0	1.0	1.0	1.0	1.0		30.4	33.3	34.2	34.9	36.2	37.8	
Total Benefits	-2,294	-6,178	-6,721	-7,541	-8,453	-8,803	-39,991	0	6,826	15,155	21,626	28,677	35,200	107,483
Net Benefits	-2,011	-5,380	-5,879	-6,602	-7,446	-7,806	-35,123	0	2,677	9,745	14,770	20,455	25,665	73,313
Benefit:Cost Ratio	8.09	7.74	7.98	8.03	8.39	8.82	8.22	N/A	1.65	2.80	3.15	3.49	3.69	3.15
Entire Industry Summary														
Total	-283	-798	-842	-939	-1,007	-998	-4,867	0	4,148	5,411	6,855	8,221	9,534	34,170
Fuel Savings (BG)	-0.808	-2.126	-2.262	-2.496	-2.756	-2.830	-13.277	0.000	2.396	5.153	7.233	9.446	11.433	35.660
Preliminary Standard (MPG)	1.0	1.0	1.0	1.0	1.0	1.0		30.4	33.3	34.2	34.9	36.2	37.8	
Final Standard (MPG)	1.0	1.0	1.0	1.0	1.0	1.0		30.4	33.3	34.2	34.9	36.2	37.8	
Total Benefits	-2,294	-6,178	-6,721	-7,541	-8,453	-8,803	-39,991	0	6,826	15,155	21,626	28,677	35,200	107,483
Net Benefits	-2,011	-5,380	-5,879	-6,602	-7,446	-7,806	-35,123	0	2,677	9,745	14,770	20,455	25,665	73,313
Benefit:Cost Ratio	8.09	7.74	7.98	8.03	8.39	8.82	8.22	N/A	1.65	2.80	3.15	3.49	3.69	3.15

Average Vehicle Price Increases												
Manufacturer	Product Plans (Do-Nothing Standard)						Preferred Alternative					
	2011	2012	2013	2014	2015	2016	2011	2012	2013	2014	2015	2016
MFR-1	-275	-661	-861	-849	-834	-818	0	316	251	307	390	496
MFR-2	0	0	0	0	0	0	0	632	656	799	854	923
MFR-3	-22	-83	-76	-74	-72	-69	0	794	1,043	1,129	1,270	1,358
MFR-4	-188	-171	-166	-161	-157	-152	0	293	505	587	668	964
MFR-5	-286	-456	-445	-489	-476	-464	0	157	196	255	443	855
MFR-6	0	0	0	0	0	0	0	559	591	768	744	838
MFR-7	-97	-215	-205	-203	-198	-191	0	413	472	988	1,385	1,361
MFR-8	-189	-197	-191	-177	-168	-166	0	644	620	1,588	1,875	1,831
MFR-9	0	0	0	0	0	0	0	110	144	177	235	277
MFR-10	-52	-176	-173	-170	-173	-168	0	552	896	1,127	1,302	1,323
MFR-11	-298	-361	-748	-751	-731	-710	0	243	258	370	532	924
MFR-12	-30	-92	-91	-88	-102	-97	0	1,641	1,537	1,533	1,713	1,884
MFR-13	0	0	0	0	0	0	0	119	323	707	723	832
MFR-14	-14	-12	-46	-45	-43	-42	0	242	625	779	794	1,005
MFR-15	0	0	0	0	0	0	0	31	29	41	121	126
MFR-16	0	0	0	0	0	0	0	33	98	205	273	456
MFR-17	-289	-362	-413	-570	-570	-555	0	160	198	564	944	1,252
Average	-46	-91	-88	-92	-95	-92	0	505	573	690	799	907

Appendix B.5   Effects Report

The summary of effects for each scenario is organized into sections. The first section, shown by example in Table 40, 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 40. Effects Report - Energy Consumption (Sample)

Model Year		2012 Total			2016 Total		
		Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Energy Consumption							
Lifetime Fuel Consumption (k gal.)	Gas	66,688,033	-3,545,420	(5%)	73,605,159	-12,798,740	(15%)
	Diesel	1,173,474	1,149,833	4864%	1,396,293	1,365,817	4482%
	Total	67,861,507	-2,395,587	(3%)	75,001,452	-11,432,923	(13%)
Sales	Gas	8,932,706	-186,617	(2%)	10,611,783	-215,409	(2%)
	Diesel	190,030	186,617	5467%	219,955	215,409	4739%
	Total	9,122,736	0	- %	10,831,738	0	- %
Lifetime VMT (k mi.)	Gas	1,739,313,905	-32,006,200	(2%)	2,183,097,373	-16,188,072	(1%)
	Diesel	39,488,498	38,832,569	5920%	47,881,842	46,967,519	5137%
	Total	1,778,802,403	6,826,369	0%	2,230,979,215	30,779,447	1%
Average Fuel Economy (mpg)	Gas	32.61	1.05	3%	37.11	5.25	16%
	Diesel	42.03	7.34	21%	42.83	5.33	14%
	Total	32.77	1.20	4%	37.21	5.35	17%

The second 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 41. 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 42 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 42. Effects Summary - Emissions (Sample)

Model Year		2012 Total			2016 Total		
		Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Emissions							
CO2 (mmT)	LDGV	620	-21	(3%)	694	-107	(13%)
	LDDV	5	4	1443%	5	5	1362%
	LDGT1	108	-18	(14%)	109	-33	(23%)
	LDDT1	10	10	- %	12	12	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	742	-25	(3%)	821	-123	(13%)
CO (tons)	LDGV	5,723,676	-25,474	(0%)	7,171,099	38,731	1%
	LDDV	8,140	7,688	1702%	10,028	9,407	1514%
	LDGT1	1,566,259	-169,580	(10%)	1,692,146	-178,229	(10%)
	LDDT1	3,686	3,686	- %	4,313	4,313	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	7,301,761	-183,679	(2%)	8,877,586	-125,778	(1%)
VOC (tons)	LDGV	472,280	-11,483	(2%)	546,792	-54,234	(9%)
	LDDV	785	740	1651%	962	902	1486%
	LDGT1	95,668	-13,529	(12%)	98,553	-21,496	(18%)
	LDDT1	2,484	2,484	- %	2,935	2,935	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	571,217	-21,787	(4%)	649,242	-71,893	(10%)
NOX (tons)	LDGV	298,371	-4,112	(1%)	360,238	-15,027	(4%)
	LDDV	1,005	943	1531%	1,234	1,153	1416%
	LDGT1	109,483	-12,787	(10%)	119,236	-15,830	(12%)
	LDDT1	5,193	5,193	- %	6,180	6,180	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	414,051	-10,764	(3%)	486,888	-23,524	(5%)
PM (tons)	LDGV	26,082	-497	(2%)	30,270	-2,162	(7%)
	LDDV	292	275	1623%	362	339	1470%
	LDGT1	5,901	-768	(12%)	6,048	-1,089	(15%)
	LDDT1	461	461	- %	548	548	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	32,735	-530	(2%)	37,227	-2,365	(6%)
SOX (tons)	LDGV	69,519	-2,342	(3%)	77,873	-11,970	(13%)
	LDDV	433	405	1443%	529	492	1362%
	LDGT1	12,104	-1,997	(14%)	12,216	-3,695	(23%)
	LDDT1	959	959	- %	1,128	1,128	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	83,015	-2,975	(3%)	91,746	-14,045	(13%)

The third and fourth sections 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 effect".

- *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. Section III.C.6 of the primary text discusses these types of costs and benefits in greater detail, and Appendix A (Model Inputs) discusses corresponding input assumptions.

Appendix B.5.1   Optimized Industry Report

The Optimized Industry Report can be generated for optimization runs by the Model. The report shows the parameters used for the target CAFE stringencies for the modeling years, as shown in Table 44 as well as graphing the net benefits curve for the stringencies examined for the optimization modeling, as shown in **Error! Reference source not found.**.
Optimization modeling is discussed in Appendix C below.

Table 43. Effects Report - Private and Social Costs and Benefits (Sample)

Model Year	2012 Total			2016 Total		
	Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Undiscounted Owner and Societal Costs (k $)						
Total Lifetime Pretax Fuel Expenditures	188,730,869	-6,572,810	(3%)	224,043,957	-33,971,499	(13%)
Fuel Tax Revenues	25,949,107	-883,559	(3%)	27,977,660	-4,230,855	(13%)
Travel Value	-491,142	-491,142	- %	-2,448,833	-2,448,833	- %
Refueling Time Value	-546,227	-546,227	- %	-2,373,575	-2,373,575	- %
Petroleum Market Externalities	10,901,612	-384,839	(3%)	12,048,608	-1,836,642	(13%)
Congestion Costs	94,470,900	356,250	0%	118,669,386	1,631,631	1%
Noise Costs	1,778,802	6,826	0%	2,230,979	30,779	1%
Accident Costs	41,704,670	163,193	0%	52,214,268	723,157	1%
CO2	19,365,738	-643,342	(3%)	23,275,884	-3,487,441	(13%)
CO	0	0	- %	0	0	- %
VOC	907,093	-34,598	(4%)	1,030,996	-114,166	(10%)
NOX	2,638,335	-68,586	(3%)	3,102,451	-149,892	(5%)
PM	9,535,460	-154,346	(2%)	10,843,888	-688,866	(6%)
SOX	3,122,609	-111,920	(3%)	3,451,009	-528,296	(13%)
Discounted Owner and Societal Costs (k $)						
Total Lifetime Pretax Fuel Expenditures	153,135,109	-5,290,393	(3%)	182,660,550	-27,654,900	(13%)
Fuel Tax Revenues	21,475,935	-725,373	(3%)	23,167,441	-3,498,016	(13%)
Travel Value	-395,984	-395,984	- %	-1,996,859	-1,996,859	- %
Refueling Time Value	-451,717	-451,717	- %	-1,971,929	-1,971,929	- %
Petroleum Market Externalities	8,978,167	-314,565	(3%)	9,927,540	-1,511,175	(13%)
Congestion Costs	77,876,272	291,974	0%	97,873,633	1,344,201	1%
Noise Costs	1,465,498	5,589	0%	1,839,047	25,341	1%
Accident Costs	34,336,766	133,475	0%	43,015,543	594,969	1%
CO2	15,666,654	-515,904	(3%)	18,846,077	-2,819,827	(13%)
CO	0	0	- %	0	0	- %
VOC	724,635	-27,540	(4%)	825,146	-93,344	(10%)
NOX	2,070,163	-52,294	(2%)	2,442,849	-120,173	(5%)
PM	7,584,574	-116,827	(2%)	8,695,017	-561,383	(6%)
SOX	2,571,696	-91,464	(3%)	2,843,520	-434,645	(13%)

Appendix B.6   Optimized Industry Report

Appendix C (below) discusses use of the model to estimate the "optimal" stringency of CAFE standards. This operating mode involves incrementally increasing the stringency of the standards over a range, estimating corresponding costs, fuel savings, CO_2 emission reductions, and benefits at each iteration. Table 44 shows a sample of industry-level reporting. Average required CAFE levels for each iteration are shown in the "Standards" section, with resultant average achieved fuel economy levels shown under "CAFE", and resultant incremental costs (relative to the baseline standards) shown under "Tech Costs". Estimated optimal stringencies (e.g., for MY2012, index number 75, producing an average required CAFE of 26.3 mpg) are shown in the "Optimized" section.

Table 44. Optimized Industry Report - Data (Sample)

Optimized	A	B	C	D	Stnd	Index	
2011	27.1	21.1	56.4	4.3			
2012	31.1	23.0	0.0	0.0	26.3	75	
2013	33.0	24.0	0.0	0.0	27.7	73	
2014	34.9	25.0	0.0	0.0	29.1	73	
2015	36.7	25.9	0.0	0.0	30.3	75	
2016	37.9	26.5	0.0	0.0	31.1	76	
Standards	0	1	2	3	4	5	6
2011							
2012	22.0	22.0	22.1	22.1	22.2	22.2	22.3
2013	23.0	23.1	23.1	23.2	23.2	23.3	23.3
2014	24.0	24.0	24.1	24.1	24.2	24.3	24.3
2015	24.7	24.7	24.8	24.9	24.9	25.0	25.1
2016	25.2	25.2	25.3	25.4	25.4	25.5	25.6
CAFE							
2011							
2012	24.1	24.1	24.1	24.1	24.1	24.1	24.1
2013	26.4	26.4	26.4	26.4	26.4	26.4	26.4
2014	27.8	27.8	27.8	27.8	27.8	27.8	27.8
2015	29.1	29.1	29.1	29.1	29.1	29.1	29.1
2016	30.3	30.3	30.3	30.3	30.3	30.3	30.3
Tech Costs							
2011							
2012	-90.9	-90.9	-90.9	-90.9	-90.9	-90.9	-90.9
2013	3,346.0	3,346.0	3,346.0	3,346.0	3,346.0	3,346.0	3,346.0
2014	5,518.1	5,518.1	5,518.1	5,518.1	5,518.1	5,518.1	5,518.1

The optimized industry report also produces graphs of numerous measures (*e.g.*, incremental costs, incremental benefits) versus stringency. Figure 10 (below) shows a sample graph in which net benefits (relative to baseline standards) are plotted versus average required CAFE levels for each model year during MY2012-2016.

Figure 10. Optimized Industry Report - Net Benefits Graph (Sample)

Industry-NBGraph
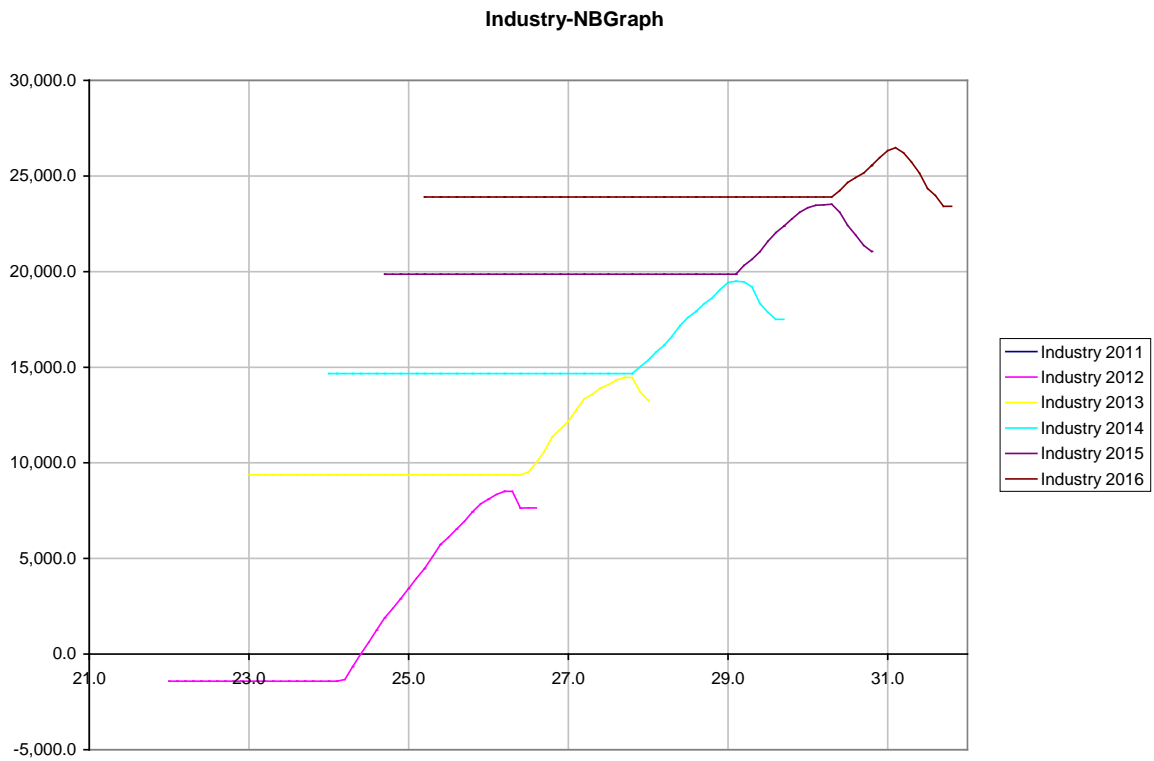
Appendix C "Optimization" of CAFE Standards

The modeling system contains algorithms that may be used to "optimize" the average stringency (that is, the average required fuel economy) of an attribute-based system by estimating the stringency at which a given condition is met. "Optimizing" the stringency, in the current modeling system, is done either by estimating the stringency level at which net societal benefits are maximized (maximum net benefits), or by finding the level where the absolute value of net benefits is minimized, after the maximum has occurred (total cost equals total benefits).[23] Optimization of CAFE Standards may be set up and run using directions provided in the shown in Appendix E below.

Using the functional form defined in the scenarios file, the optimized stringency for either the passenger car or light truck fleet is determined for the entire industry, and for each year, by adjusting the function's upper and lower limits at a user-specified increment, for a given number of iterations above and below the initial shape.[24] To ensure the correct "carry-over" of technology costs and improvements, the model years are optimized sequentially. At the end of each model year, the system re-runs the entire passenger car or light truck fleet using the optimized stringency, then carries the costs and improvements into the next year.

With the varying asymptotes, the system examines new iterations (or trials), performing typical compliance modeling, holding the function's shape constant while altering the stringency. At the end of each iteration, the model calculates and saves the final technology costs, fines owed, benefits, fuel savings, and benefit-cost ratios for each manufacturer and industry overall. Once all iterations have been processed, the modeling system calculates the stringency by finding the first iteration that satisfies the net-benefit-maximizing or absolute-value-of-net-benefit-minimizing criterion.

Below, Figure 11 illustrates how the model maximizes net benefits. The plot on the left shows curves specifying fuel economy targets for three iterations (*i.e.,* stringency levels) examined under a sample optimization. For each of these iterations, colored points in the plot on the right show the corresponding stringency (in terms of average required fuel economy) and the calculated net benefits (in $m). The black line in the plot on the right shows stringency and net benefits for all other iterations included in the optimization. In this example, the least stringent of the three highlighted iterations, shown in red, produces net benefits of about $2,700m at a stringency of 31.2 mpg. As stringency increases, net benefits reach a peak or maximum, shown in green, of about $3,100m at a stringency of 31.7 mpg. The corresponding curve is shown in green in the plot on the left. As stringency increases beyond this point, more expensive technologies are required, such that net

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[23] Use of the term "optimize" was first applied in this model in reference to the concept of estimating the "socially optimal" stringency—that is, the stringency producing the greatest increase in benefits relative to the increase in costs, where both benefits and costs are measured on a societal basis, excluding economic transfers such as fuel taxes and civil penalties. This approach involves maximizing net benefits. Considering public comments, NHTSA also required the availability to examine stringencies at which total costs equal total benefits (or, within the scope of available technologies, most nearly equal). As currently used, the term "optimize" refers to either approach.

[24] The model currently optimizes stringency for only one fleet (*i.e.*, passenger car or light truck) in a single model run.

benefits decrease. By the point stringency reaches 31.2 mpg, shown in blue, net benefits fall to about $2,800m.

Figure 11. Maximizing Net Benefits
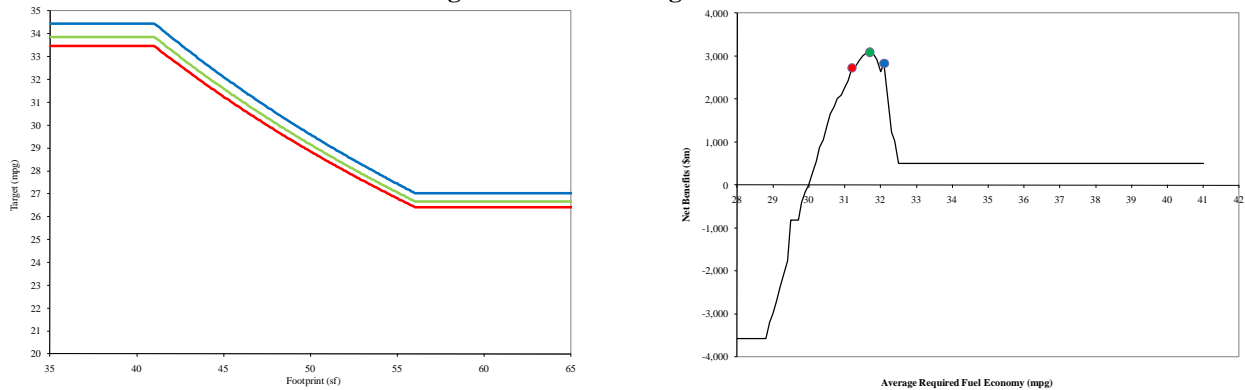
This example also illustrates a scenario in which net benefits stop decreasing before total costs equal total benefits (when total costs equal total benefits, net benefits equal zero). In this example, all available technologies are exhausted when stringency reaches 32.5 mpg, at which point net benefits are about $500m. Once technologies are exhausted, no additional cost or benefits will be realized – the manufacturer's fleet will remain static. Above this stringency, civil penalties are incurred. However, as economic transfers, civil penalties are not counted as costs to society. Therefore, net benefits do not change as stringency increases beyond 32.5 mpg.

The last step of the modeling process is to use the optimized standard (*i.e.*, the standard defined by the user-specified shape and then shifted vertically by the model to produce the optimized stringency) to obtain the corresponding fleet (*i.e.*, the fleet that reflects estimated manufacturer responses at the optimized stringency) for the model year. As under standard (*i.e.*, non-optimizing) modeling exercises, this step is necessary to properly carry over added technologies from one model year to the next.

As originally designed, the model only performed optimization by accounting for each manufacturer separately, and then using the industry-wide sum of manufacturer-specific results to estimate optimal stringency. In the current version, the model also provides an optional setting to merge the fleet (*i.e.*, combine the vehicles of all individual manufacturers into a single group) throughout the optimization process. As explained below, under some circumstances, this option can provide more stable optima than when accounting for each manufacturer separately. The effect of this setting is illustrated below for a hypothetical fleet involving two manufacturers: "OEM1," a "laggard" which produces a fleet of vehicles with generally low baseline fuel economy relative to fuel economy targets; and "OEM2," a "front runner" which produces a fleet of vehicles with generally high baseline fuel economy relative to fuel economy targets. Typically, a manufacturer with a "laggard" fleet will experience application of technologies to its fleet at a lower stringency than that of a manufacturer with a more fuel efficient fleet. This will result in a different shape net benefits curve, as well as a different placement of the peak of maximum net benefits.

Below, Figure 12 shows net benefits (attributable separately to OEM1 and OEM2) on the y axis, with stringency (in terms of the average required fuel economy) on the x axis. As stringency increases (moving from left to right on the chart), OEM1, shown in orange, begins to be impacted by new standards when the average stringency (*i.e.*, the average fuel economy required of the industry) reaches 29.0 mpg.[25] For OEM1, net benefits increase as stringency increases past 29.0 mpg, peak when stringency reaches 31.9 mpg, decline as stringency continues to increase, and stabilize when stringency increases beyond past 32.8 mpg, at which point OEM1 exhausts all available technology applications. For OEM2, shown in blue, net benefits do not begin to increase until stringency increases past 34.3 mpg. Subsequently, net benefits attributable to OEM2 peak when stringency reaches 40.1 mpg, decline as stringency continues to increase, and stabilize when stringency increases beyond past 41.2 mpg, at which point OEM2 exhausts all available technology applications.

Figure 12. Net Benefits versus Stringency for Hypothetical 2-Manufacturer Fleet
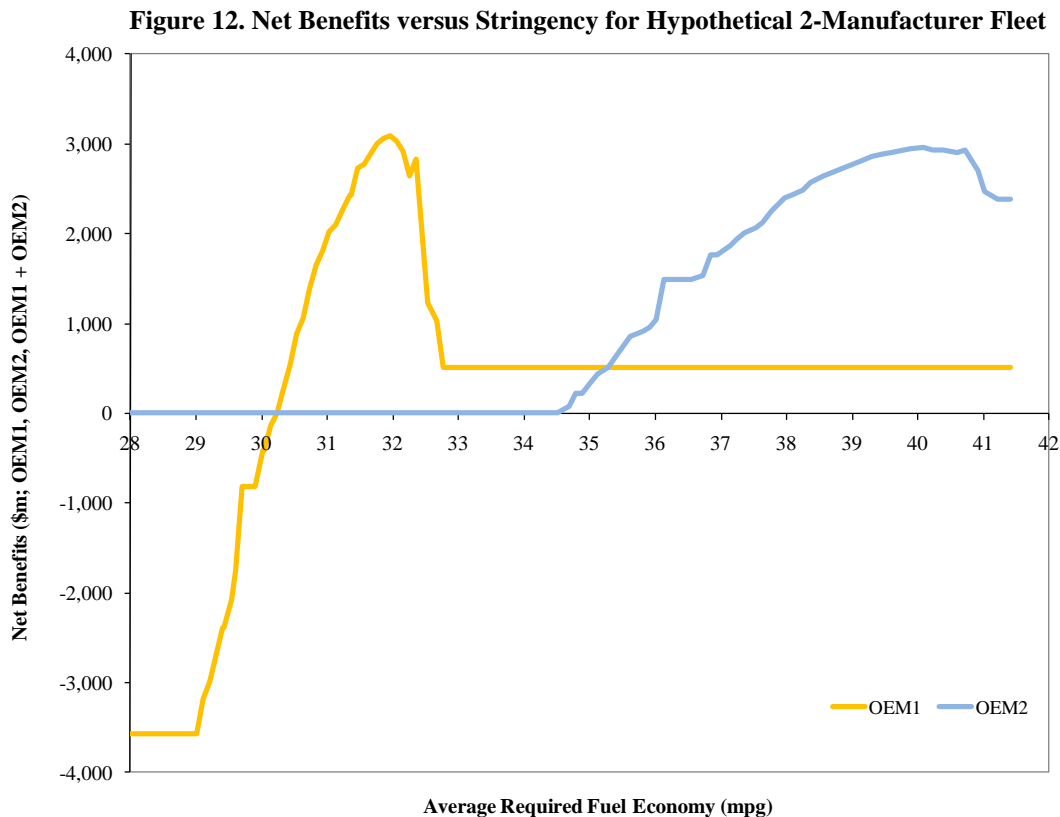
Figure 13 shows the corresponding total net benefits for the industry (*i.e.*, the sum of net benefits attributable to both OEM1 and OEM2) as a dashed line superimposed on the net benefits attributable separately to OEM1 and OEM2. In this example, the significant difference between OEM1 and OEM2 in terms of baseline performance as compared to targets causes the total net benefits for the industry to exhibit two distinct peaks, one at 32.8 mpg and one at 40.1 mpg. Below 34.3 mpg, OEM2 is unaffected, such that results for

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[25] At stringencies of about 29.0-30.2 mpg, net benefits attributable to OEM1 are negative. This indicates the market forecast for OEM1 fell short of the baseline standards, and that for OEM1, standards of 29.0-30.2 mpg (again, in terms of average fuel economy required of the industry) would require technology beyond that required under the market forecast for OEM1, but not as much as would be required under the baseline standards.

OEM1 account for all of the net benefits for the industry. Above 34.3 mpg, the net benefits attributable to OEM2 are augmented by approximately $500m in net benefits attributable to OEM1 once OEM1 has exhausted available technologies (at 32.8 mpg).[26]   In this example, relative sales volumes are such that the "OEM2 peak" at 40.1 mpg is dominant. However, if OEM1's market share had been somewhat greater than in this example, the "OEM1" peak at 32.8 mpg would have been dominant.

Figure 13. Sum of Net Benefits Attributable to OEM1 and OEM2
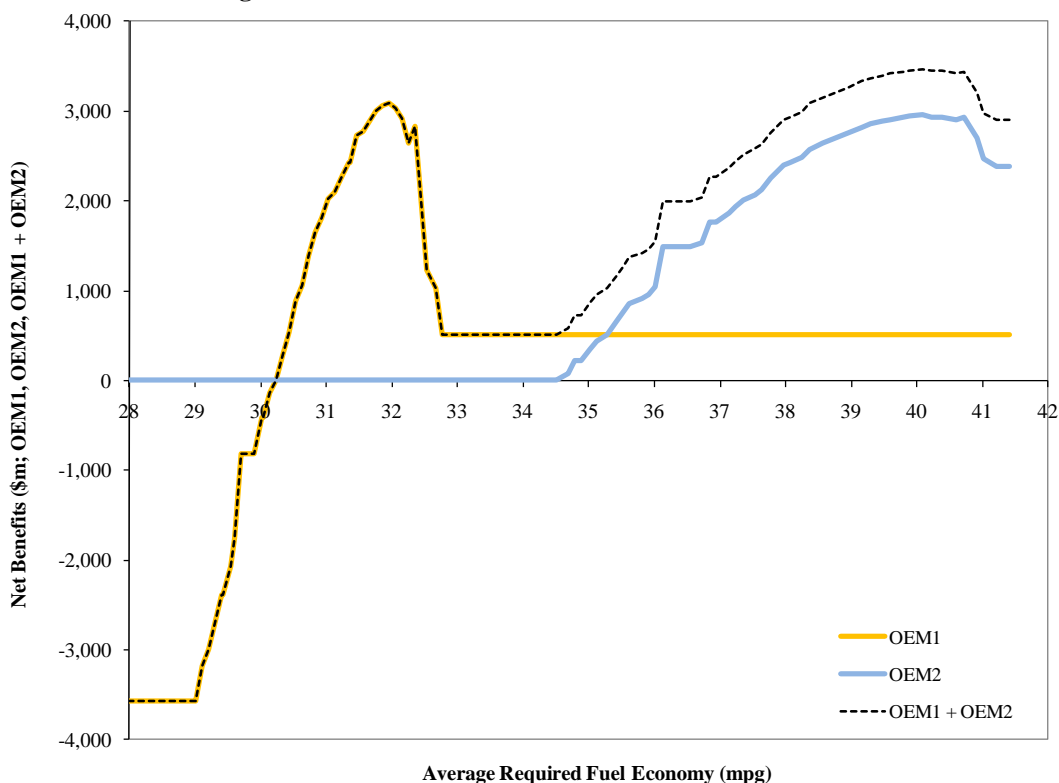
For the same hypothetical fleet, Figure 14 demonstrates the effect of selecting the "Merge the fleet before optimizing" setting when running the model. With distinctions between OEM1 and OEM2 removed, the baseline average fuel economy of the merged fleet exceed are 30.2 mpg and technologies are not required until average stringency reaches 30.3 mpg. This higher average fuel economy is because the relatively high performance of OEM2's fleet balances the relatively low performance of OEM1's fleet. Net benefits subsequently increase, peak at 33.8 mpg, and then decline (except for a slight secondary peak at 34.2 mpg) until all technology options are exhausted when stringency reaches 34.4 mpg.

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[26] If a manufacturer exhausts available technologies without achieving compliance with a given standard, the model calculates the resultant civil penalties. However, because civil penalties are economic transfers, the model does not add these to estimated costs; therefore, the plot of net benefits attributed to an individual manufacturer becomes flat at stringencies beyond the point where the manufacturer exhausts available technology options.

Figure 14. Net Benefits for Hypothetical Merged Fleet
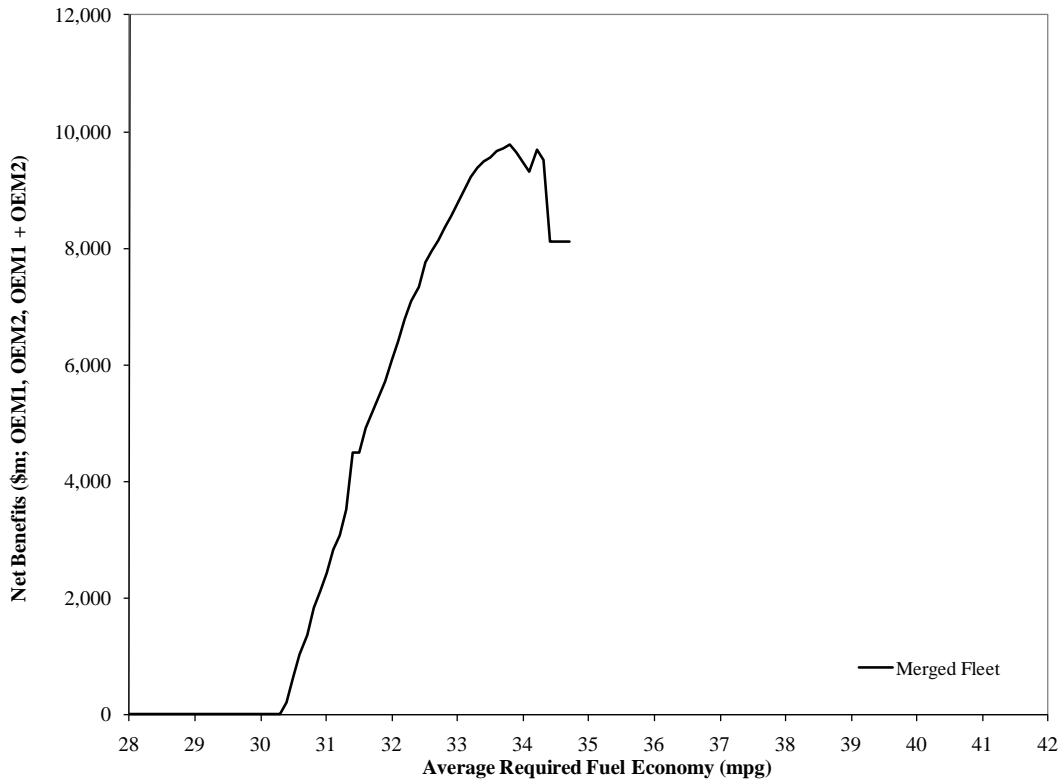
Figure 15 compares the net benefits obtained with the merged fleet to those obtained for the underlying individual manufacturers, and for the industry as represented maintaining the distinction between the two manufacturers. Without merging the fleet, the model obtains a net benefits plot that has two widely separated peaks. Because the relative heights of these peaks could be impacted differently by relatively modest changes in model inputs (including manufacturers' market shares and sometimes other inputs), these widely separated peaks lead to unstable (albeit correctly calculated) results. For example, relatively modest changes in model inputs such as manufacturer sales volumes or economic factors (*e.g.*, discount rate, rebound effect, fuel price) can change which peak is dominant, thereby causing a significant change in estimated optimized stringency. The merged fleet produces a much more stable peak that falls between the two peaks obtained without applying this option.

Figure 15. Comparison of Net Benefits with and without Merging of Fleet

Average Required Fuel Economy (mpg)

OEM1
OEM2
OEM1 + OEM2
Merged Fleet
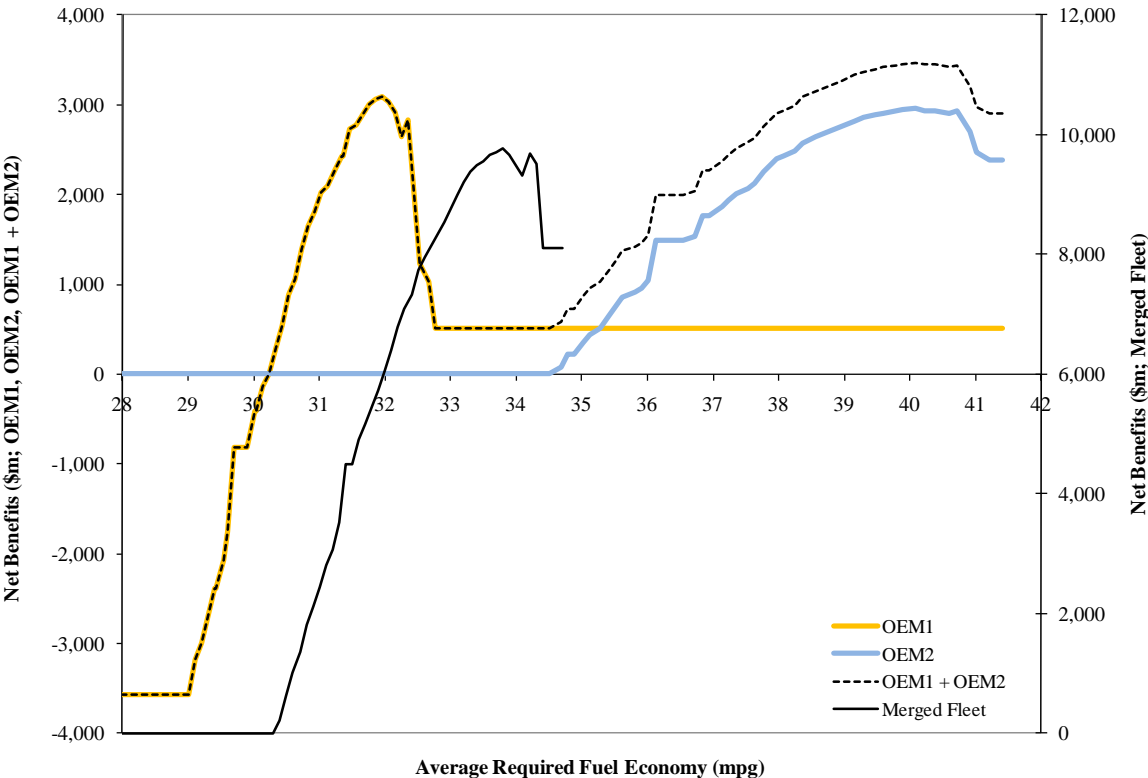
Appendix D   Monte Carlo Analysis

Uncertainty analysis (e.g., 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, military security, and carbon dioxide costs). Monte-Carlo analysis may be set up and run using directions provided in the **CAFE Model Software Manual** document.

The results of the analysis are located in the output folder selected during modeling. Unlike other model runs, Monte-Carlo simulation does not produce formatted Excel reports. Instead, plain text Monte-Carlo log files can be found under the "MC-logs" subdirectory. As with regular modeling runs, however, the per-scenario logs are numbered in order of appearance, starting at 0, with the first scenario (0) being the baseline to which all others are compared. The following files are generated at the end of the Monte-Carlo simulation:

- *MC_trials.csv*:   Contains pseudo-randomly generated Monte-Carlo trials used as input to the analysis. The contents of the file are summarized in Table 45.

- *MC_tech_costs.csv*: Specifies the sales-weighted average technology costs for each technology, adjusted by the randomized cost scales from the **MC_trials.csv** file. The average costs for a technology are computed across all vehicle technology classes that were used during modeling as follows:

$$TECHCOST_t = \left(\frac{\sum_{i,MY}(SALES_i \times COST_{i,t})}{\sum_{i,MY} SALES_i} \right) \times SCALE_t$$

  where $SALES_i$ represent the sales of vehicle i, $COST_{i,t}$ is the base (unadjusted) cost of technology t as it applies to vehicle i, and $SCALE_t$ is the randomized value specifying the amount by which to scale the technology cost of technology t.

- *MC_tech_fcs.csv*:   Specifies the sales-weighted average technology fuel consumption improvements for each technology, adjusted by the randomized fuel consumption scales from the **MC_trials.csv** file. The average fuel consumption improvements for a technology are computed across all vehicle technology classes that were used during modeling as follows:

$$TECHFC_t = \left(\frac{\sum_{i,MY}(SALES_i \times FC_{i,t})}{\sum_{i,MY} SALES_i} \right) \times SCALE_t$$

  where $SALES_i$ represent the sales of vehicle i, $FC_{i,t}$ is the base (unadjusted) fuel consumption improvement of technology t as it applies to vehicle i, and $SCALE_t$ is the randomized value specifying the amount by which to scale the technology fuel consumption improvement of technology t.

- *MC_Sn*_data.csv*: Includes the results of pseudo-randomly generated Monte-Carlo trials for all scenarios. The log file for the results of the baseline scenario (0) provides the totals accrued during that scenario. The log files for the results of non-baseline scenarios (Sn1, Sn2, …) contain changes compared to the baseline. The contents of the file are summarized in Table 46.

Table 45. MC_Trials.csv Contents

Column	Contents
Index	Unique index of the trial.
FuelPriceEstimates	Randomized pretax fuel prices; the probabilities are: 50% for average fuel prices and 25% for and high prices.
DiscountRate	Value of the discount rate examined with each trial.
ReboundEffect	Randomized value of the rebound effect.
CO2Estimates	Randomized carbon diaxide cost estimates; the probabilites are: 50% for average cost estimates, 25% for low, 20% for high, and 5% for very high.
MonopsonyCost	Randomized value of the monopsony cost.
PriceShockCost	Randomized value of the price shock cost.
MilitarySecurityCost	Randomized value of the military security cost.
Cost(Technology)	Randomized value specifying the amount by which to scale the technology costs for each technology.
FC(Technology)	Randomized value specifying the amount by which to scale the technology fuel consumption improvement for each technology.

Table 46. MC_Sn*_data.csv Contents

Column	Contents
Index	Unique index of the trial.
DiscountRate	Value of the discount rate examined with each trial.
AvePrice_MFR*(MY)	Average regulatory costs accumulated by the manufacturers for each model year.
TechCost_MFR*(MY)	Total technology costs accumulated by the manufacturers for each model year.
TechCost(MY)	Total technology costs accumulated by the entire industry for each model year.
SocialBenefits(MY)	Discounted social benefits accumulated by the entire industry for each model year.
FuelSavings(MY)	Fuel savings accumulated by the entire industry for each model year.
BCRatio(MY)	Ratio of social benefits to total technology costs for each model year.

Appendix E   CAFE Model Software Manual

Appendix E.1   Warnings

This software was developed for analysis by U.S. Department of Transportation staff of potential fuel economy requirements.

This software uses input files containing detailed information regarding vehicles manufactured for sale in the United States and creates output files containing similarly detailed information regarding such vehicles. If input files containing information in any way (e.g., based on entitlement under 5 U.S.C 552 to confidential treatment) protected from disclosure to the public are used, some output files created by this software must also be protected from disclosure to the public.

Appendix E.2   Notice

Some of the icons and/or images used by the CAFE Compliance and Effects Modeling System may have been obtained from www.kde-look.org and are the sole property of their respective owners.

To the best of our knowledge, all images are distributed under the GNU GPL or the GNU LGPL licenses. If any of the icons violate the original author's copyright or terms of use, please contact the current administrators of the CAFE Model project.

Appendix E.3   Installation and System Requirements

The CAFE Compliance and Effects Modeling System (abbreviated: CAFE Model) runs on IBM-compatible computers using the Microsoft® Windows operating system. Although the software does not have strict hardware requirements, beyond what is needed to run the operating system, a 1 GHz or faster Intel compatible processor, with at least 1 GB of physical RAM is strongly recommended. The software has been developed and tested on computers using Windows XP and Windows Server 2003, but may operate properly on machines using older versions of Windows (e.g., Windows 2000), or newer versions (e.g., Windows Vista/7), as long as a compatible Microsoft® .NET Framework is installed.

Because the software makes extensive use of Microsoft® Excel files for input and output, Excel must be installed on the system. To provide a means of protecting confidential business information (CBI) contained in input and output files (if the user is relying on CBI), the software makes use of encryption algorithms available in Excel 2003. These algorithms are not available in older versions of Excel. Unencrypted files, however, may be used with such versions.

The software uses the Microsoft® .NET Framework, version 1.1. If the Framework is not already present, it must be installed. Instructions for downloading and installing the .NET framework are available on the Internet at http://msdn.microsoft.com/netframework/downloads/framework1_1/.

The software also uses the Microsoft® Visual J# .NET Redistributable Package 1.1, which can be obtained on the Internet at http://msdn.microsoft.com/en-us/vjsharp/bb188598.aspx.

Based on the characteristics of machines used in the development of this software, the following table provides a summary of system requirements:

Table 47. CAFE Model System Requirements

Intel compatible processor (1 GHz or faster recommended)
512 MB RAM (1 GB recommended)
10 MB hard drive space for installation (additional disk space will be required during runtime)
Microsoft® Windows XP Microsoft® Windows Server 2003 Microsoft® Windows Server 2008
Microsoft® .NET Framework 1.1
Microsoft® Visual J# 1.1 Redistributable
Microsoft® Office 2003 or later.

Once the system requirements have been met, the latest version of the CAFE Model may be obtained by contacting NHTSA or Volpe Center staff. Prior to installation, make sure that all previous version of the model are removed from the computer as described in the Appendix E.4, Removing/Repairing a CAFE Model Installation section below.

To install the software, place the setup files on the desktop and execute Setup.Exe[27]. Follow the on-screen instructions provided by the wizard. After installation completes, the setup files may be deleted from the computer.

The installer places a shortcut for the modeling system on the desktop as well as creates a Start Menu entry under **Start > Programs > CAFE Model**.

Appendix E.4   Removing/Repairing a CAFE Model Installation

The CAFE Model installation may be removed or repaired at any time by going to **Start > Programs > CAFE Model > Uninstall CAFE Model**.   To remove the modeling system completely, select the "Remove CAFE Model" option in the dialog box that appears. If the application is misbehaving, the "Repair CAFE Model" option may be selected instead. Click Finish and wait for the remove/repair process to complete.

Appendix E.5   CAFE Model Graphical User Interface

The CAFE Model Graphical User Interface (GUI) provides users with a set of tools necessary to set up and run multiple modeling test scenarios, which are commonly referred to as CAFE Model sessions. Each CAFE Model session can be configured independently, each with its own set of model inputs and settings. Once configured, the session may be

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[27] The setup files provided may be in a zip archive, which will need to be extracted using a zip utility such as WinZip (www.winzip.com) or 7Zip (www.7-zip.org).

saved for future runs, or executed immediately.[28]   When the model runs, the system displays the progress of the compliance modeling process in each session's window.

The model GUI consists of two primary screens: the main **CAFE Model** window and the **Modeling Settings** window. The **CAFE Model** window is used for managing the modeling sessions, while the **Modeling Settings** window is used to configure them.

To run the modeling system, click on the **CAFE Model** shortcut located on the desktop, or go to **Start > Programs > CAFE Model > CAFE Model**. When the application launches, a **Warnings** dialog box is displayed (Figure 16). The user must read and understand the warnings listed prior to using the modeling system.
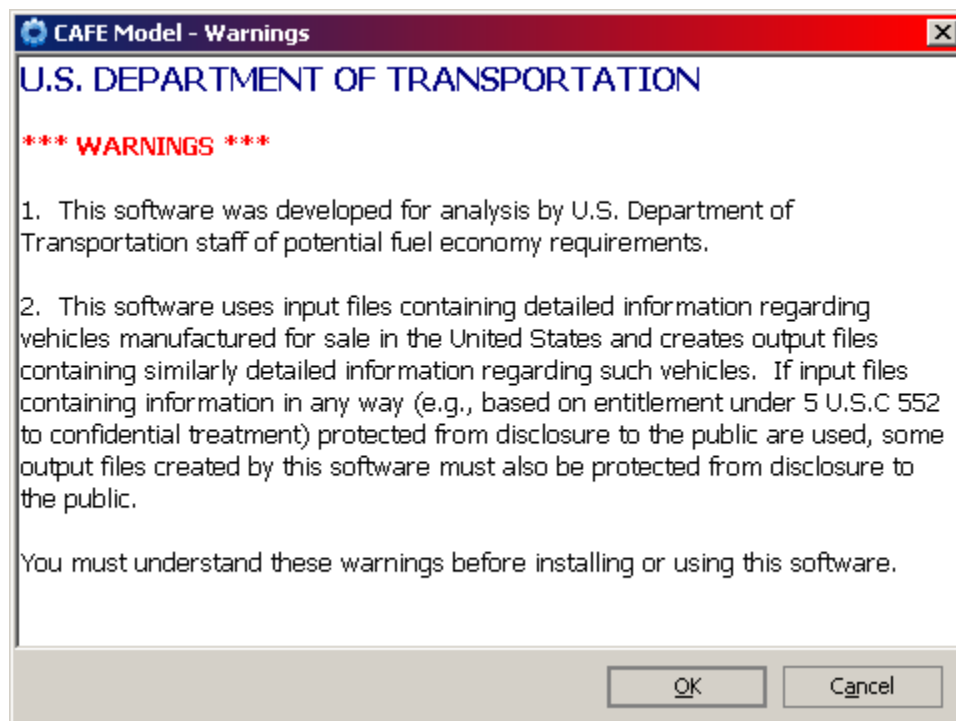
Figure 16. Warnings Dialog Box

After clicking the **OK** button in the **Warnings** dialog box, the main **CAFE Model** window, described below, opens.

Appendix E.6   CAFE Model Window

The main **CAFE Model** window (Figure 17) is used to create, configure, and manage CAFE modeling sessions. The main window also controls the model operation, allowing users to start and stop modeling simulation, as well as to generate modeling reports.

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[28] It is recommended that users save the sessions prior to running them in order to assign a meaningful title to each session.
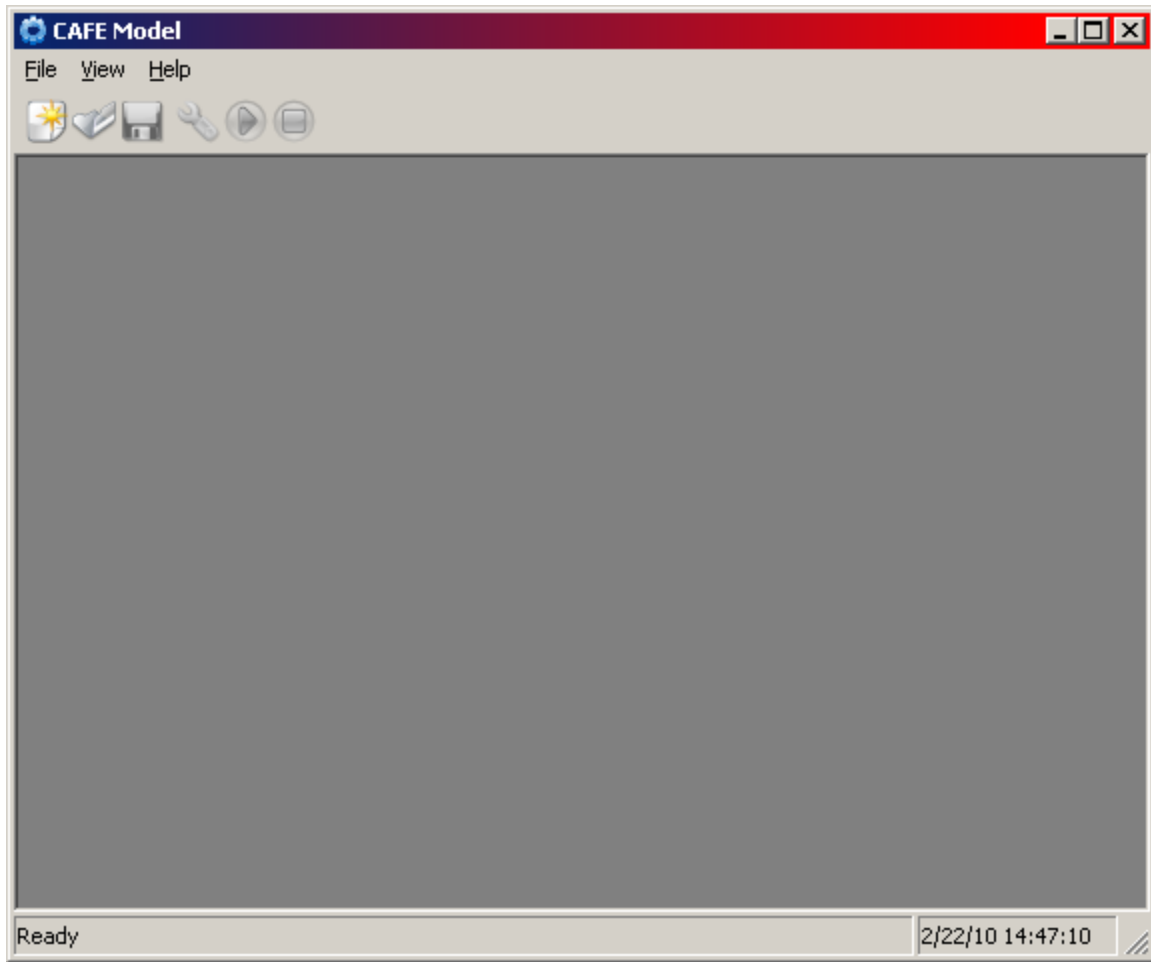
Figure 17. CAFE Model Window

When the model first starts up, most of the menu items and toolbar icons are disabled, until a new session is created, or an existing one is opened.

The model GUI is operated using a simple, easy to use file-menu (Figure 18), with most commonly used shortcuts also available on the model toolbar (Figure 19). For user convenience, most of the menu entries may also be controlled using keyboard shortcuts.
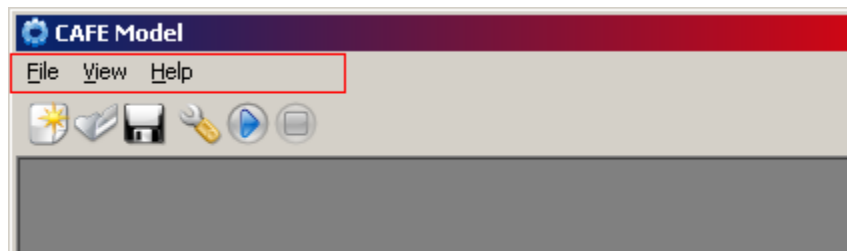
Figure 18. CAFE Model File Menu
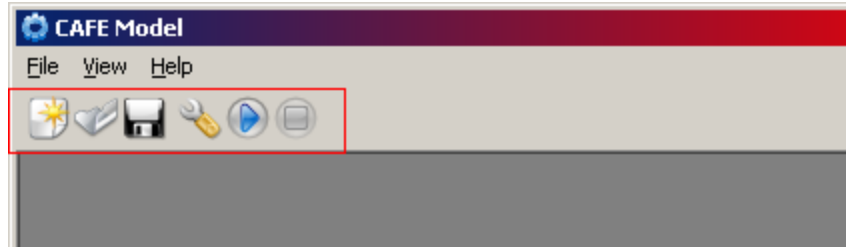
Figure 19. CAFE Model Toolbar

Some of the most commonly used file menus are:

- *File > New Session*: Creates a new CAFE Model Session and displays the **Modeling Settings** window to the user.

- *File > Open Session*: Opens an existing CAFE Model Session.

- *File > Close Session*: Closes the active CAFE Model Session.

- *File > Save Session*: Saves the active CAFE Model Session.

- *File > Start Modeling*: Begins the modeling process for the active CAFE Model Session.

- *File > Stop Modeling*: Suspends the modeling process of the active CAFE Model Session.

- *File > Exit*: Exits the CAFE Model. If any of the modeling sessions are still opened, they will be closed prior to exiting the model.

- *View > Modeling Settings*: Displays the **Modeling Settings** window, where all modeling options and settings can be configured.

- *View > Output Location*: Opens the Windows Explorer and browses to the location where the output files and reports of the active session are saved.

Appendix E.6.1   Modeling Settings Window

The **Modeling Settings** window contains multiple panels for configuring all of the runtime options available to the model. The user can use this window to set up a new session, or modifying an existing one, before starting the modeling process. Each of the available configuration panels is outlined in the sections below.

1. General Compliance Settings Panel

The **General Compliance Settings** panel (Figure 20) is used to specify what type of modeling the user would like to run. Each model is tailored to different type of analysis, using its own set of assumptions and configuration settings. Presently, four model types are available:

- *Standard Compliance Model*: The Standard Compliance Model is the default mode of operation for the CAFE modeling system. This model type is used to evaluate technology costs and benefits in response to the required CAFE standards defined in the modeling scenarios.

- *Maximum Technology Compliance Model*: This model type is similar to the Standard Compliance Model, except additional modeling constraints are enabled. When this model type is used, the modeling system is configured to ignore year availability of technologies, technology

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phase-in caps, and vehicle refresh and redesign years. Furthermore, each manufacturer is assumed to be unwilling to pay CAFE fines.

- *Optimization Model*: This model type should be used to perform sensitivity analysis and optimize the shape of the required CAFE standard.

- *Monte-Carlo Model*: The Monte-Carlo Model is a specialized CAFE modeling type, which is used for running customized Monte-Carlo simulations necessary for uncertainty analysis.
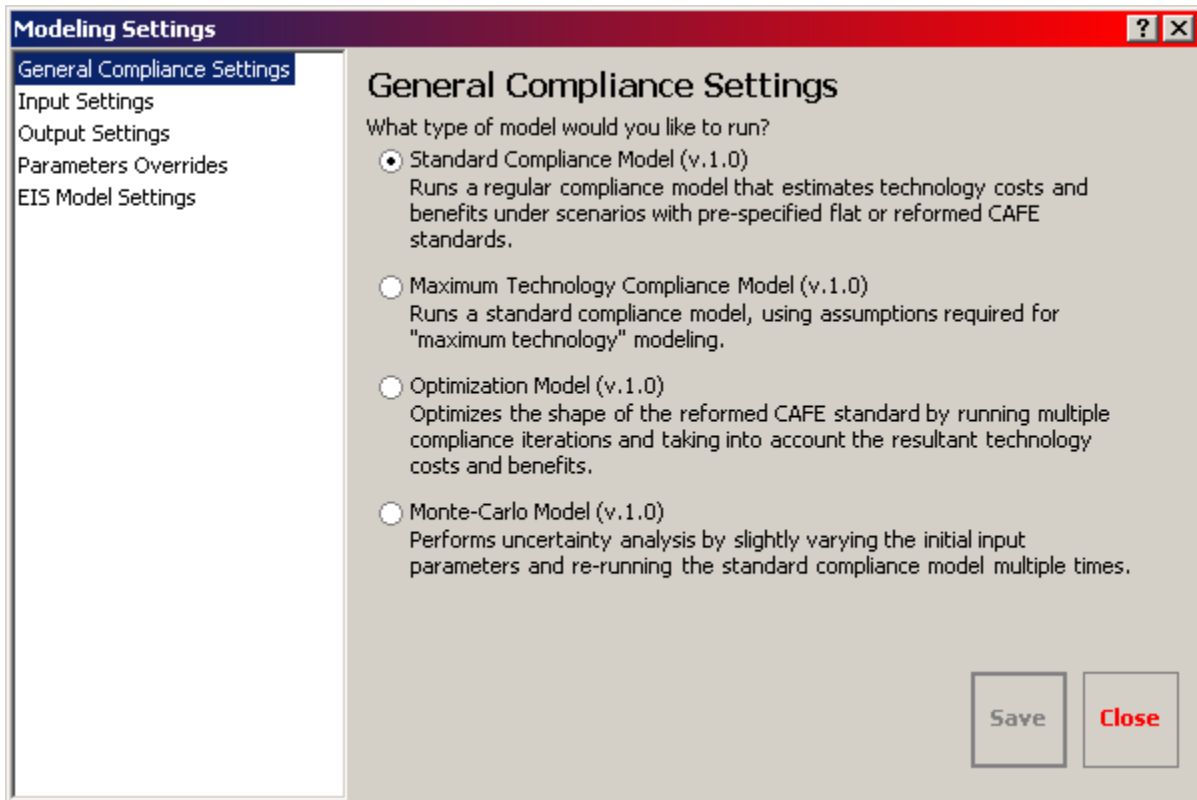
Figure 20. General Compliance Settings Panel

2. Input Settings Panel

On the **Input Settings** panel (Figure 21), the user can select the input data files for use with the modeling system. To protect Confidential Business Information (CBI), some of the input files may be password protected. The CAFE Model, therefore, provides an option for users to enter an input password prior to loading such files.
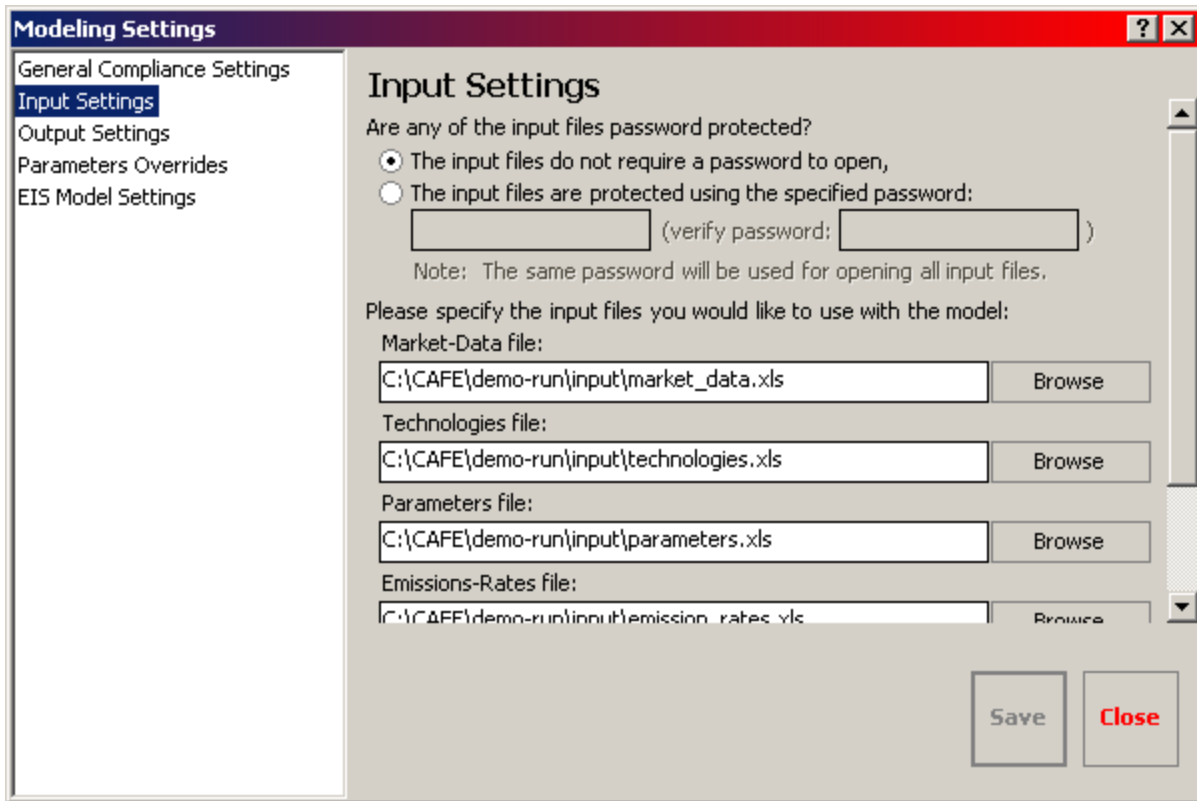
Figure 21. Input Settings Panel (1)

When selecting input files, the model will attempt to verify that an appropriate file was selected. If incorrect file path is entered, an error message will be displayed (Figure 22).
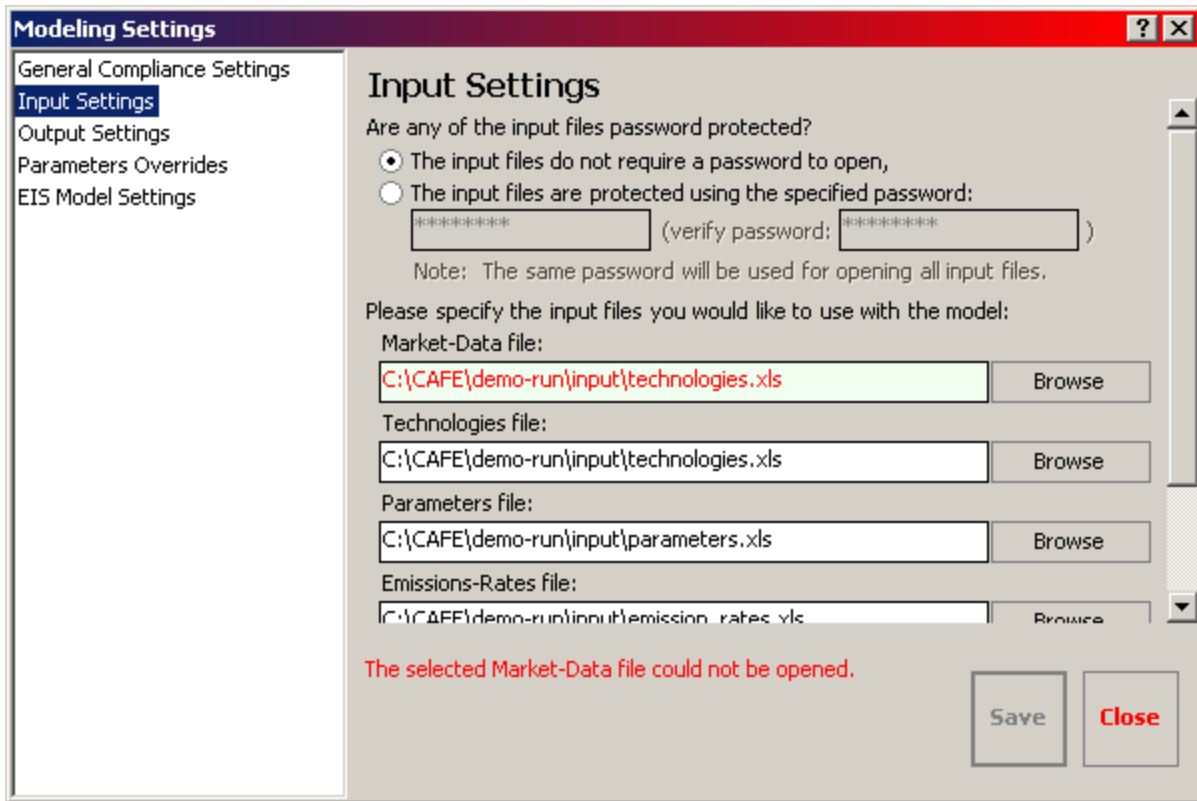
Figure 22. Input Settings Panel (2)

3.   Output Settings Panel

The **Output Settings** panel (Figure 23) is used to configure the location where modeling results will be saved and which modeling reports the CAFE Model should generate. If input data contained CBI, it may be necessary to protect outputs produced by the model. The system provides the ability to password protect the Excel reports that the model generates, however, the modeling logs are not encrypted.
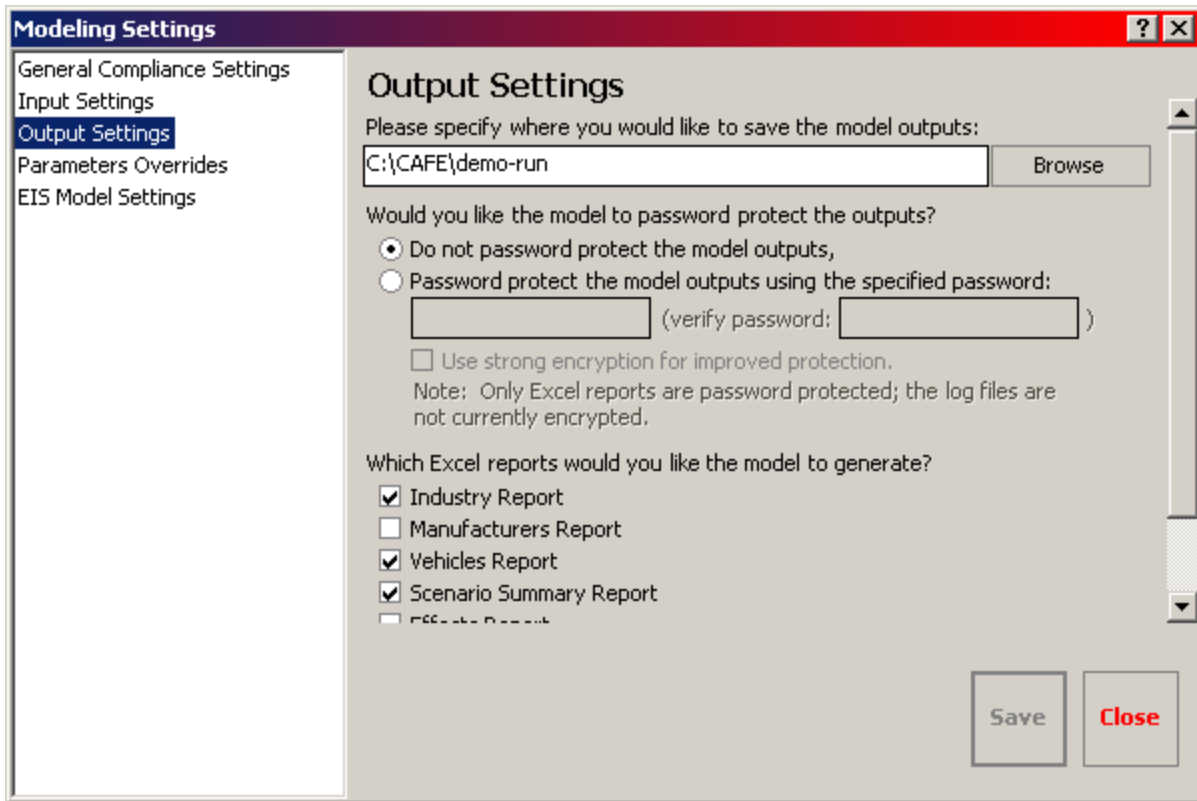
Figure 23. Output Settings Panel (1)

When password protecting the Excel reports, "strong encryption" option may be used for improved security (Figure 24).
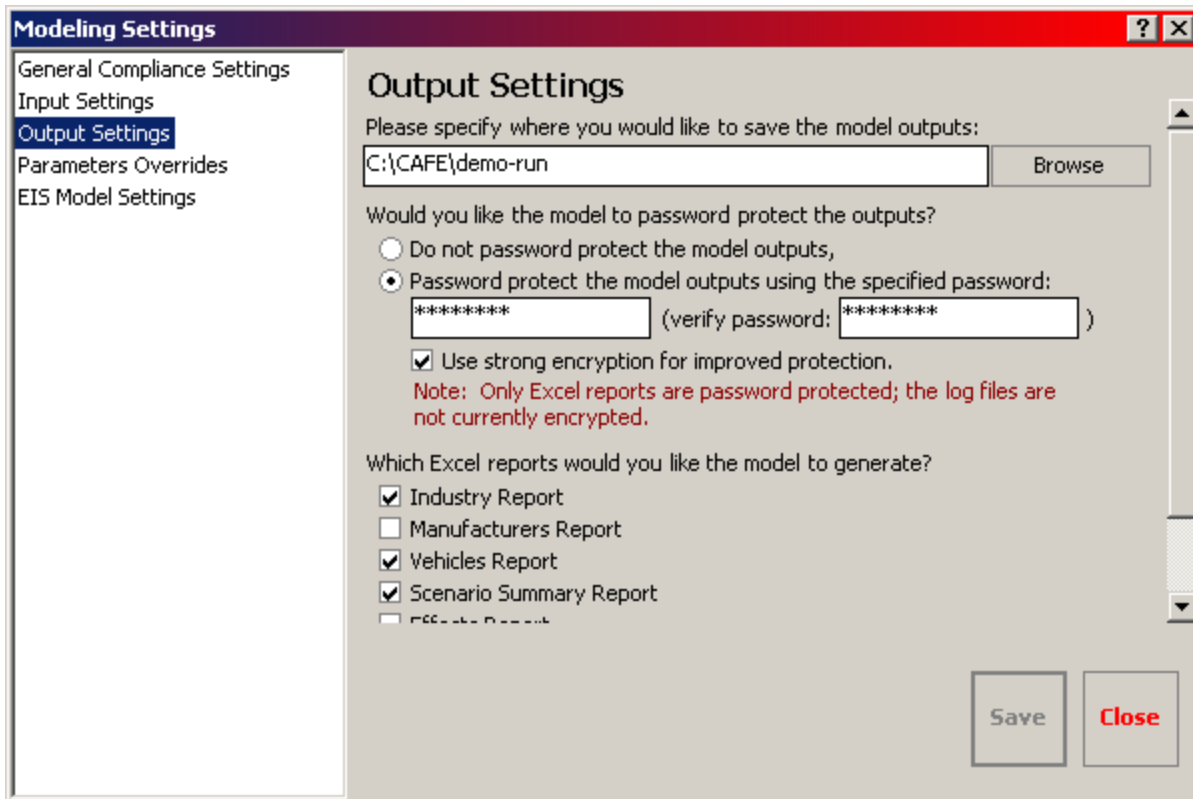
Figure 24. Output Settings Panel (2)

The modeling system is configured to generate seven different reports (Figure 25)[29]:

- *Industry Report*: Provides industry-wide and manufacturer-level summary of compliance model results. The results are grouped by manufacturer (or entire industry), with each worksheet tab showing a summary view for all model years.

- *Manufacturers Report*: Provides industry-wide and manufacturer-level summary of compliance model results. The results are grouped by model year, with each worksheet tab showing results from all manufacturers, and the combined industry values.

- *Vehicles Report*: Presents disaggregate vehicle-level summary of compliance model results.

- *Scenario Summary Report*: Displays an overview of industry-wide and manufacturer-level compliance and effects results, compared versus the baseline across all scenarios.

- *Effects Report*: Provides summary of energy and emissions effects.

- *Environmental Assessment Report*: Presents summary of fuel consumption and emissions effects, disaggregated by calendar and model year.

- *Optimized Industry Report*: Provides industry-wide and manufacturer-level technology costs, fines, and benefits, as well as carbon dioxide and fuel savings, and benefit-cost ratios, for all iterations from industry optimization. This report also graphs the socially optimized functional form (aka, optimized shape) for the entire industry by model year, and displays benefit-cost,

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[29] Note: The Monte-Carlo Model does not support any of the modeling reports provided on the Output Settings panel. Selecting any of the reports during Monte-Carlo modeling will have no effect.

marginal benefit:cost, net benefits, and optimized shape charts. **Note**: The Optimized Industry report can only be generated when running the Optimization Model.
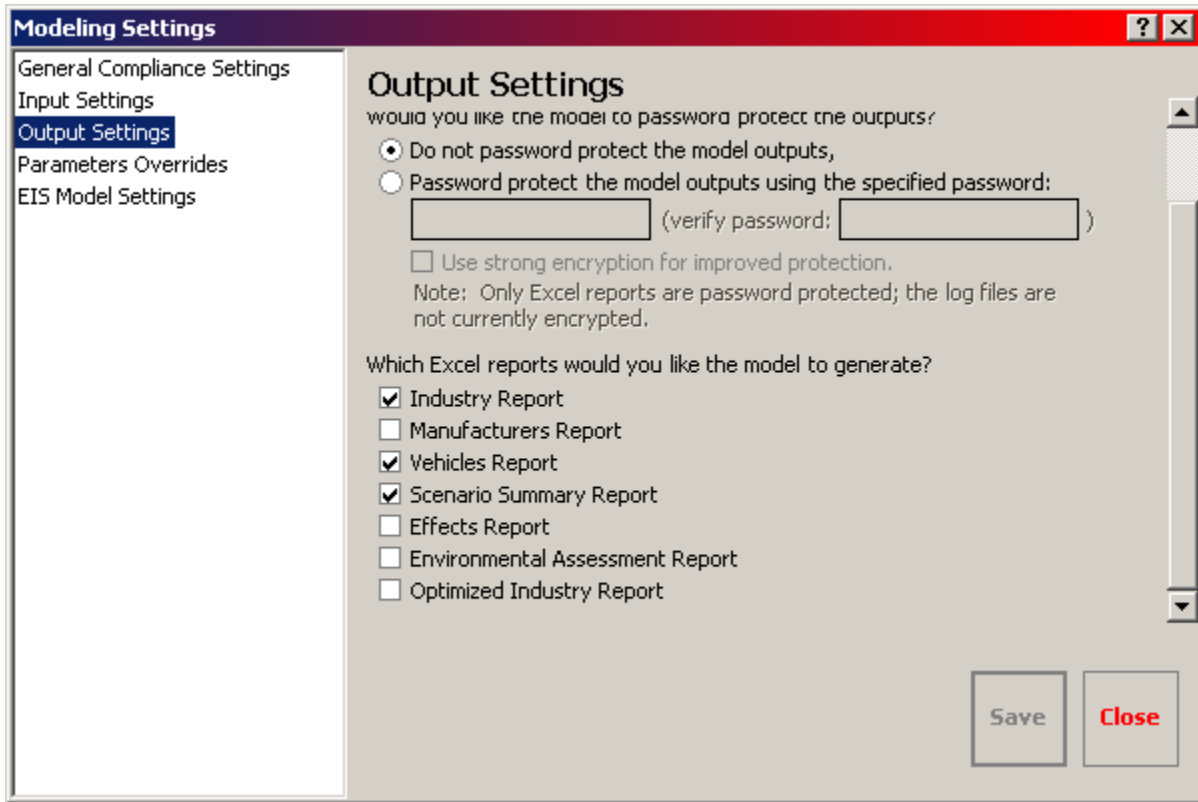
Figure 25. Output Settings Panel (3)

4. Parameters Overrides Panel

Some of the options loaded from a parameters input file may be overridden using the **Parameters Overrides** panel (Figure 26).[30] If an "override" option is checked off (not selected), a default value from the input file is used. If an override option is checked on (selected), that value will be used in place of what was loaded from the parameters file. In Figure 26 below, the options for overriding the rebound effect and the discount rate are selected, and set to 20% and 7% respectively.

The following are available parameters overrides options:

- *Override Fuel Price Estimates*: Specifies whether to use the low, average, or high fuel price estimates from the parameters input file. By default, average fuel price estimates are used.

- *Override CO_2 Estimates*: Specifies whether to use low, average, high, or very-high carbon dioxide cost estimates from the parameters input file. By default, average CO_2 cost estimates are used.

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[30] The Parameters Overrides cannot be used if the Monte-Carlo Model is selected.

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- *Override Rebound Effect*: Overrides the Rebound Effect value read in from the parameters file with a user defined value. Valid values are between -1.00 and 1.00.

- *Override Discount Rate*: Overrides the Discount Rate value read in from the parameters file with a user defined value. Valid values are between 0.00 and 1.00.

- *Override Value of Travel Time per Vehicle*: Overrides the Value of Travel Time per Vehicle value read in from the parameters file with a user defined value.

- *Override Military Security Cost*: Overrides the Military Security component of economic costs read in from the parameters file with a user defined value.

- *Scale Consumer Benefits During Effects Calculations*: Specifies whether the model should scale the private consumer benefits by a specific percentage during the effects calculations. Valid values are between 0.00 and 1.00.
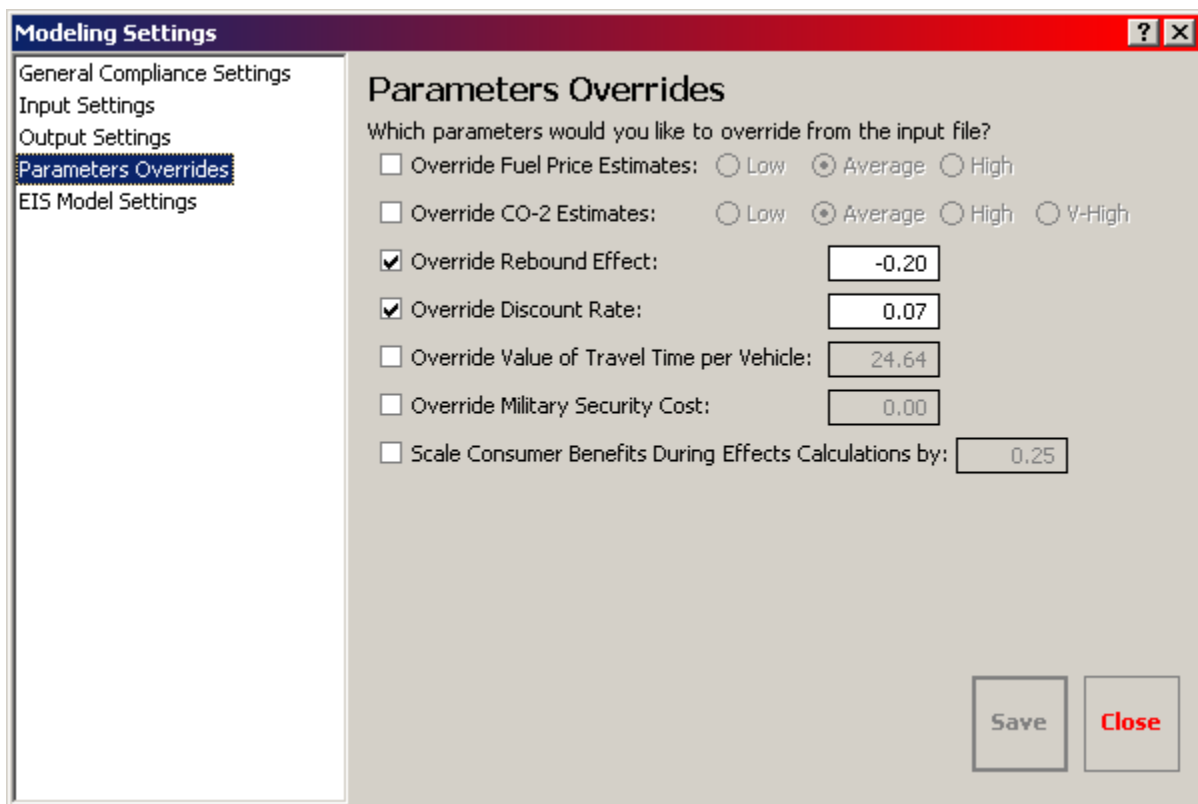
Figure 26. Parameters Overrides Panel

5. EIS Model Settings Panel

The CAFE Model includes the ability to perform supplemental analysis necessary for the Environmental Impact Statement (EIS). The system can be configured for EIS modeling using the **EIS Model Settings** panel (Figure 27).[31] There, the EIS Model is enabled by selecting the "Run the EIS Model" option, and choosing the appropriate input files required for EIS analysis.

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[31] EIS modeling cannot be run when the Optimization Model or the Monte-Carlo Model is selected.

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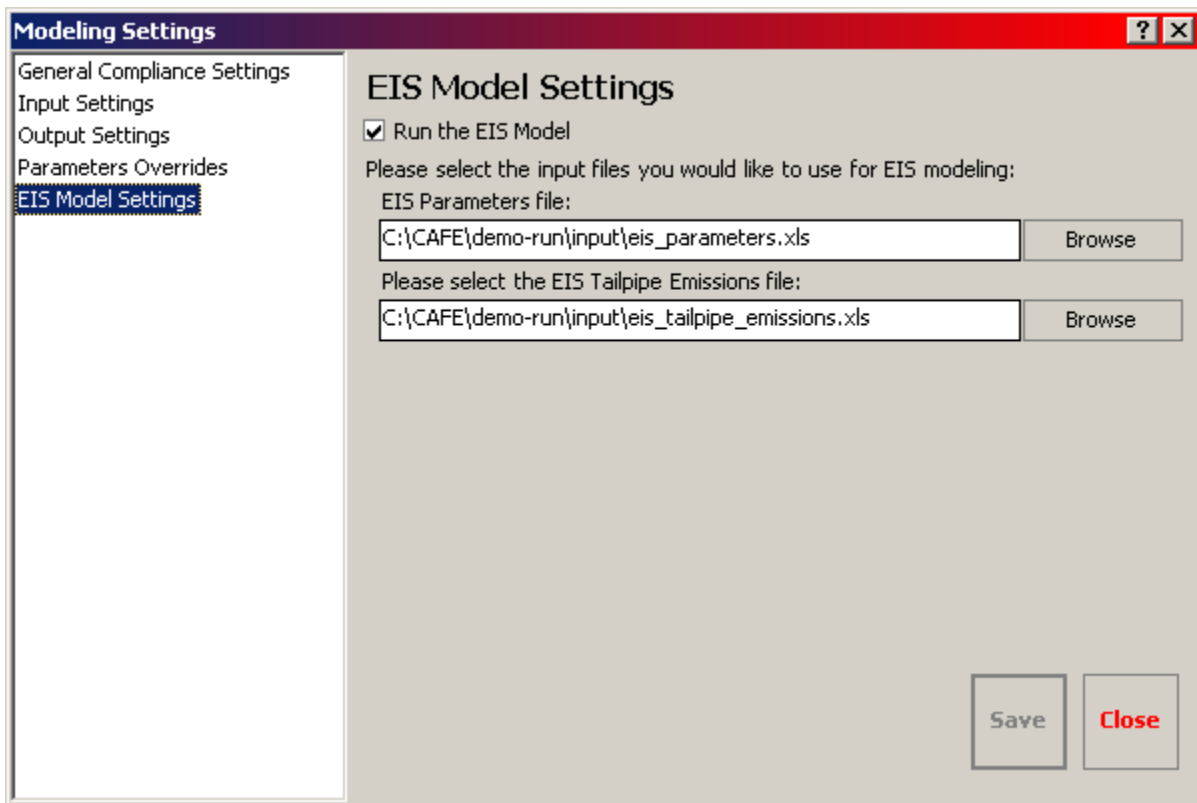
Figure 27. EIS Model Settings Panel

6. Optimization Model Settings Panel

When an Optimization Model type is selected, the **Optimization Model Settings** panel (Figure 28) becomes available. This panel provides additional options necessary for configuring the system for optimization modeling.

The first set of options determines the type of optimization – that is, which fleet the model should optimize:

- *Cars*: Forces the modeling system to optimize vehicles regulated as passenger automobiles only. If the market data input file contains any vehicles regulated as light trucks, the value of CAFE standard for those vehicles will be kept at a constant value throughout optimization.

- *Trucks*: Forces the modeling system to optimize vehicles regulated as light trucks only. If the market data input file contains any vehicles regulated as passenger automobiles, the value of CAFE standard for those vehicles will be kept at a constant value throughout optimization.

- *Auto-detect*: Allows the model to automatically determine whether to optimize passenger automobiles or light trucks. This option is useful if the market data input file contains only one class of vehicles (e.g., cars-only or trucks-only). If the market data file includes a mixed fleet of vehicles (passenger autos and light trucks), this option should not be used.

The next set of options determines the optimization mode the model should use when identifying the optimum value of the CAFE standard:

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- ***Optimize based on maximum Net Benefits***: Specifies that the optimization model should optimize the value of CAFE standard based on the difference between the discounted social benefits and technology costs, by maximizing that difference.

- ***Optimized by minimizing Net Benefits, after the maximum has occurred***: Specifies that the optimization model should optimize the value of CAFE standard based on the difference between the discounted social benefits and technology costs, by finding the lowest positive difference after the maximum difference has occurred.

Additional optimization options are:

- ***Iterations above optimum***: Indicates the number of iterations to examine above the initially calibrated shape of the target function, by moving the asymptotes upward in GPM space. Increasing the asymptotes produces a less stringent value of CAFE standard. Valid values are between 0 and 1000.

- ***Iterations below optimum***: Indicates the number of iterations to examine below the initially calibrated shape of the target function, by pushing the asymptotes down in GPM space. Decreasing the asymptotes produces a less stringent value of CAFE standard. Valid values are between 0 and 1000.

- ***Increment by***: Specifies the value at which to increment the asymptotes of the target function in GPM space. Valid values are between 0.00001 and 0.00500.

- ***Merge the fleet before optimizing***: Specifies whether to merge the entire industry into a single large manufacturer before beginning the optimization modeling process. Using this option smoothes the Net Benefits calculations and may help reduce multiple relative maximums ("peaks") caused by manufacturers with conflicting redesign schedules.
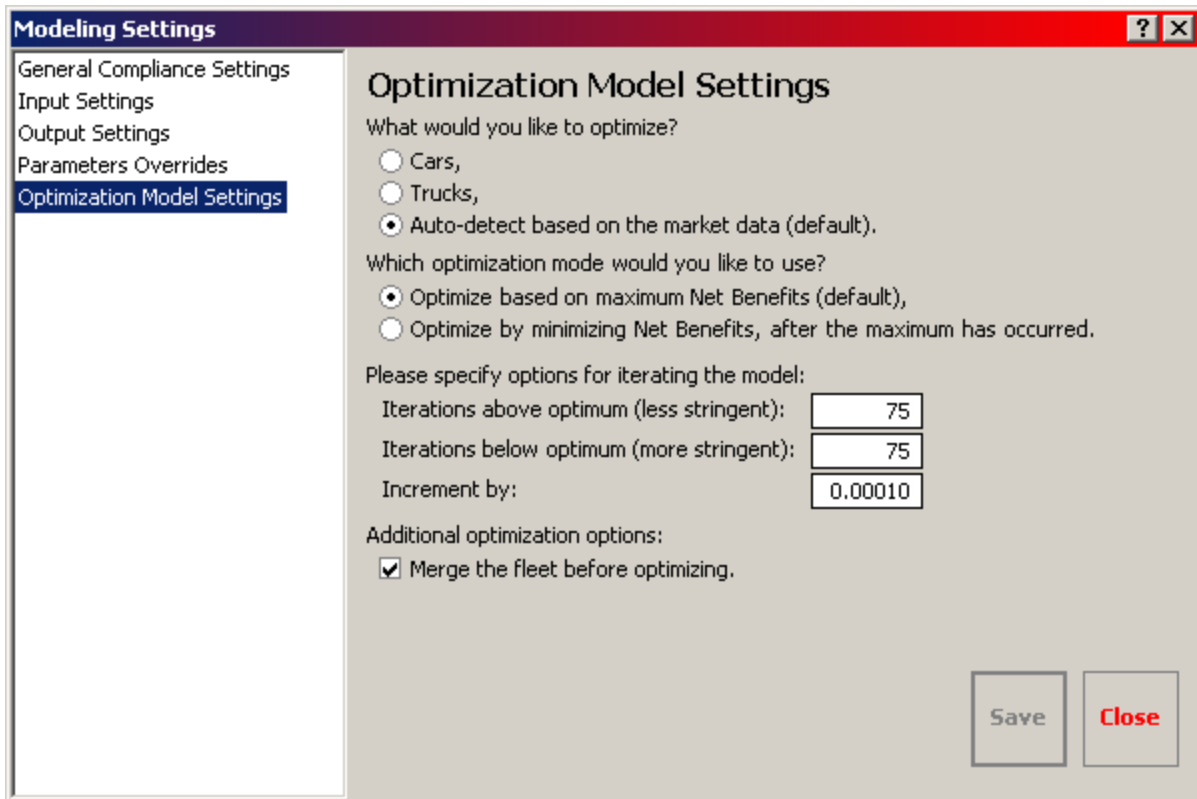
Figure 28. Optimization Model Settings Panel

7. Monte-Carlo Model Settings Panel

Selecting the Monte-Carlo Model type enables the **Monte-Carlo Model Settings** panel (Figure 29), which provides additional options required for Monte-Carlo modeling. During modeling, the system may automatically generate a new set of trial pairs to use for analysis, or use an input file that was previously generated during an earlier run. When generating trial pairs, each new trial pair may consist of multiple Monte-Carlo trials – one for each discount rate analyzed.
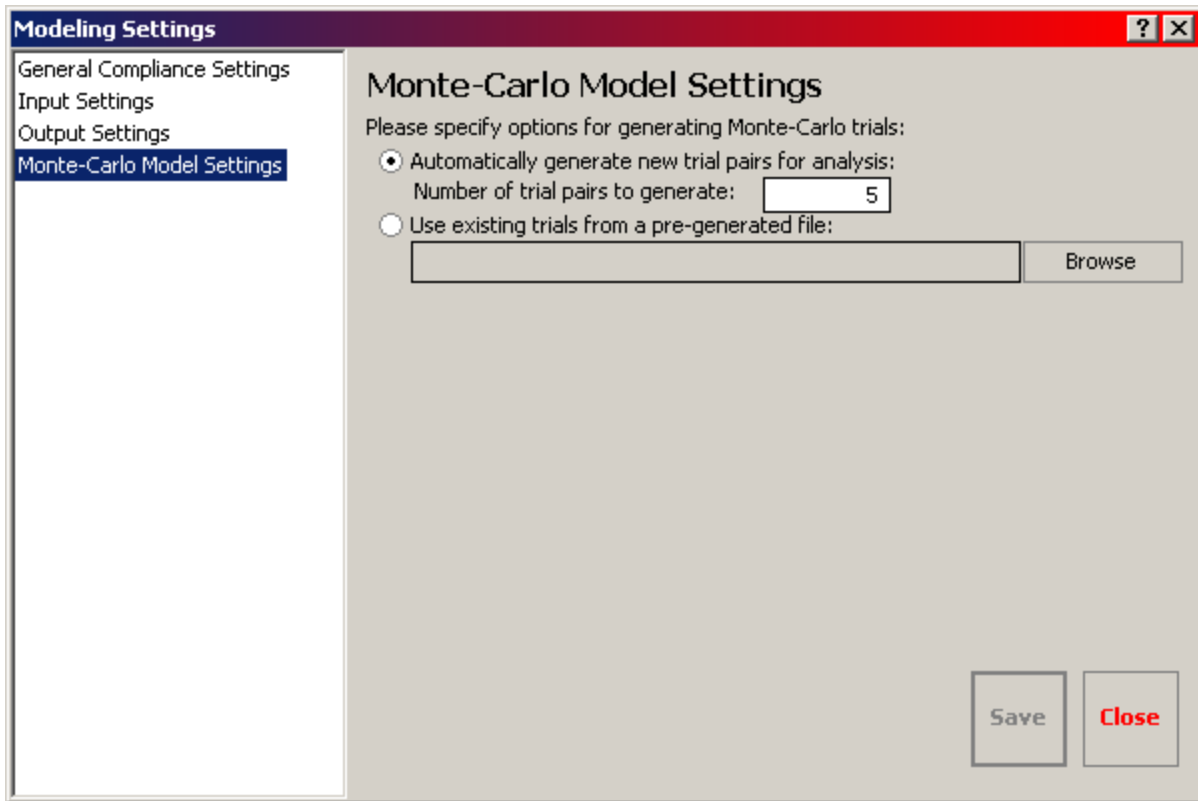
Figure 29. Monte-Carlo Model Settings Panel

Appendix E.7   CAFE Model Usage Examples

This section provides examples for configuring and running the CAFE Model sessions using various model types.

Appendix E.7.1   Example 1 – Configuring for Standard Compliance Modeling

This example demonstrates the steps necessary for configuring the modeling system to perform a regular Compliance Model run.

- Run the CAFE Model by clicking on the **CAFE Model** shortcut located on the desktop, or going to **Start > Programs > CAFE Model > CAFE Model**. Read through the **Warnings** dialog box, and then click the **OK** button.

- Select **File > New Session** to create a new modeling session. The **Modeling Settings** window appears. Note the errors at the bottom of the window; these indicate that the input files have not been selected.

- On the **General Compliance Settings** panel, select the Standard Compliance Model as in Figure 30 below.
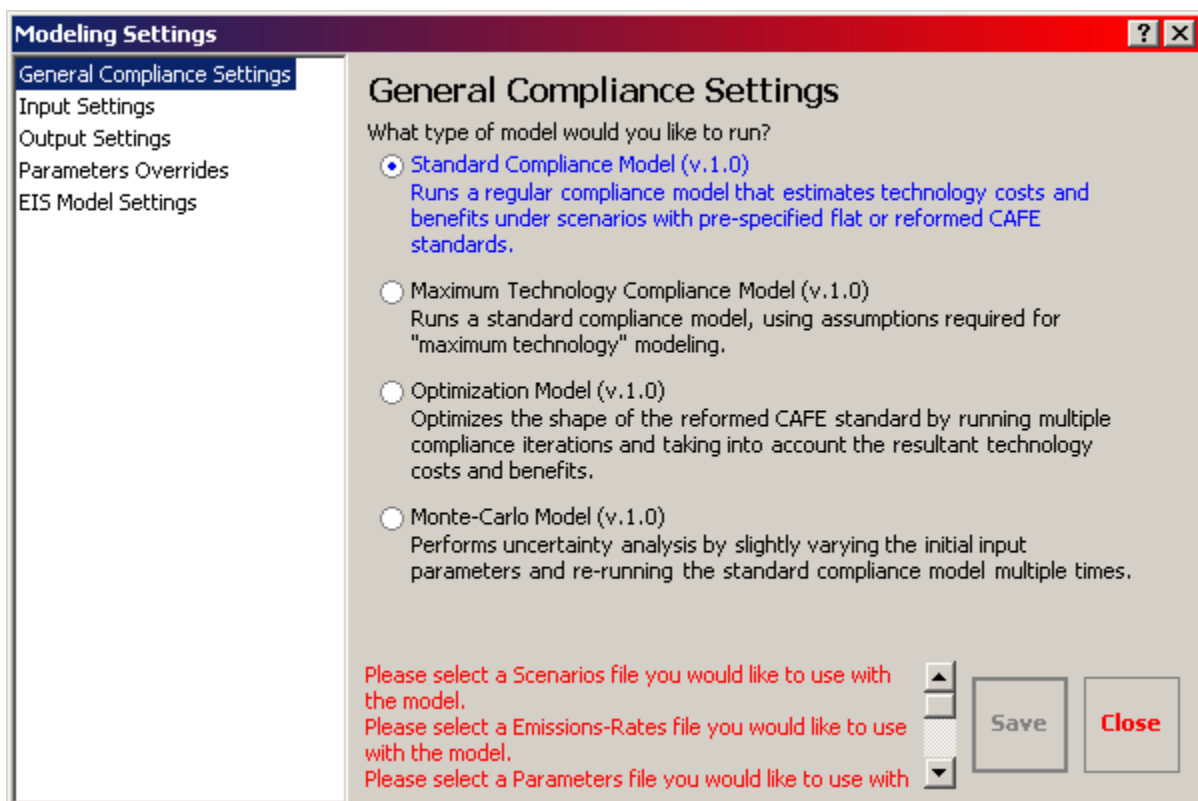
Figure 30. Select Standard Compliance Model

- Click on the **Input Settings** panel to select the input files to use for modeling (Figure 31). Note that once all the input files have been selected appropriately, the error messages disappear.
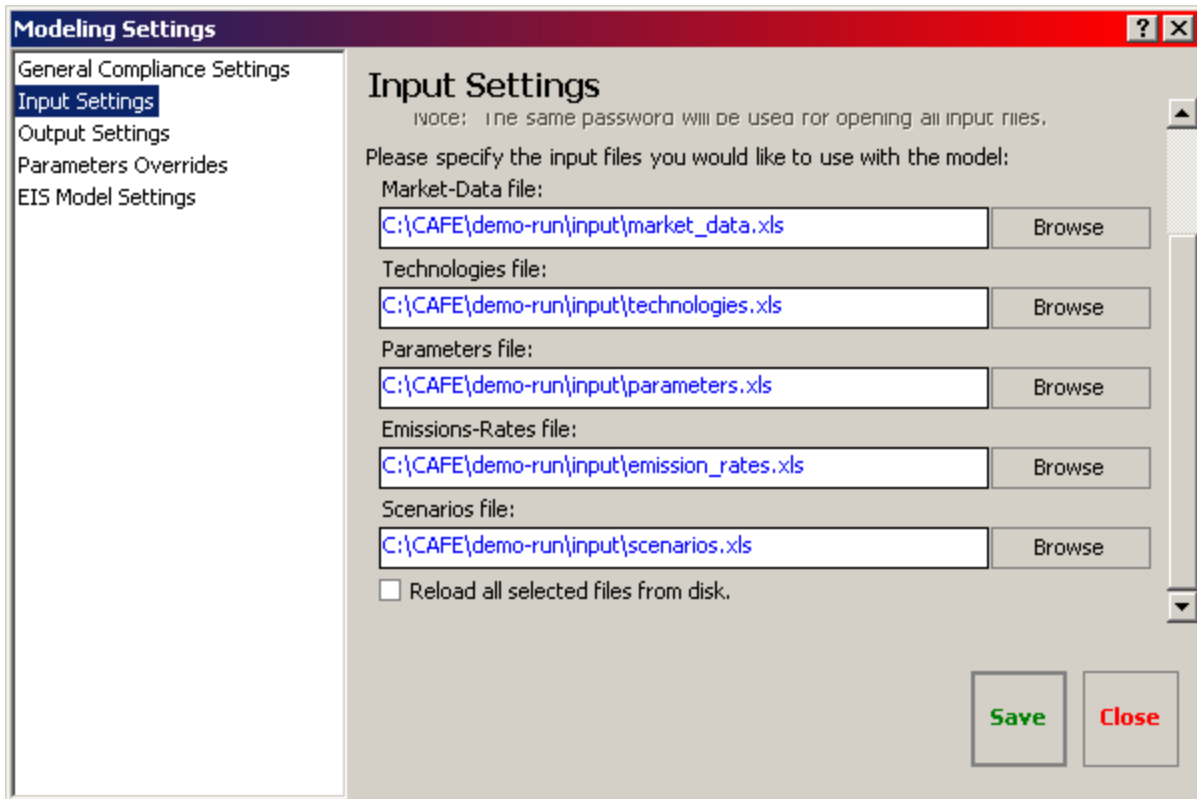
Figure 31. Select Input Files

- On the **Output Settings** panel, select the location for output files and the industry, vehicles, and scenario summary reports (Figure 32).
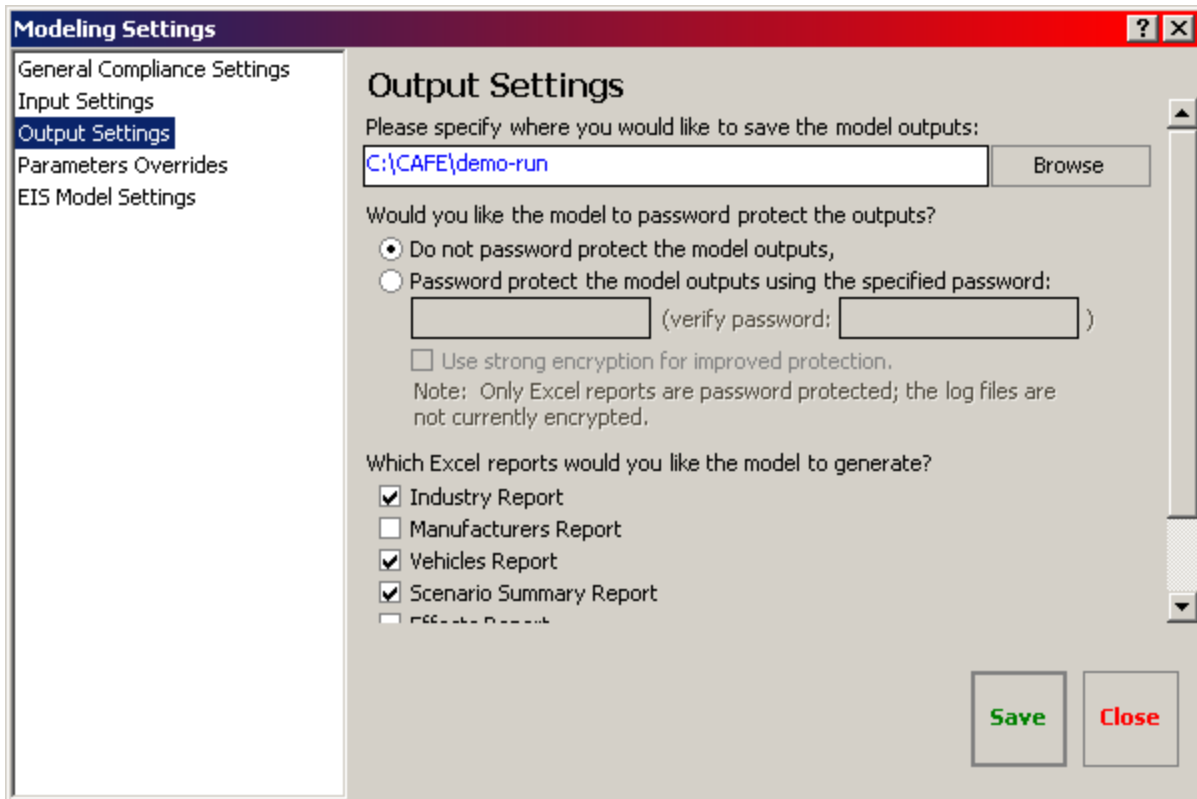
Figure 32. Select Output Location and Modeling Reports

- The **Parameters Overrides** and the **EIS Model Settings** panels are not used for this exercise.

- Click the **Save** button to save the modeling settings and load the input files (Figure 33).
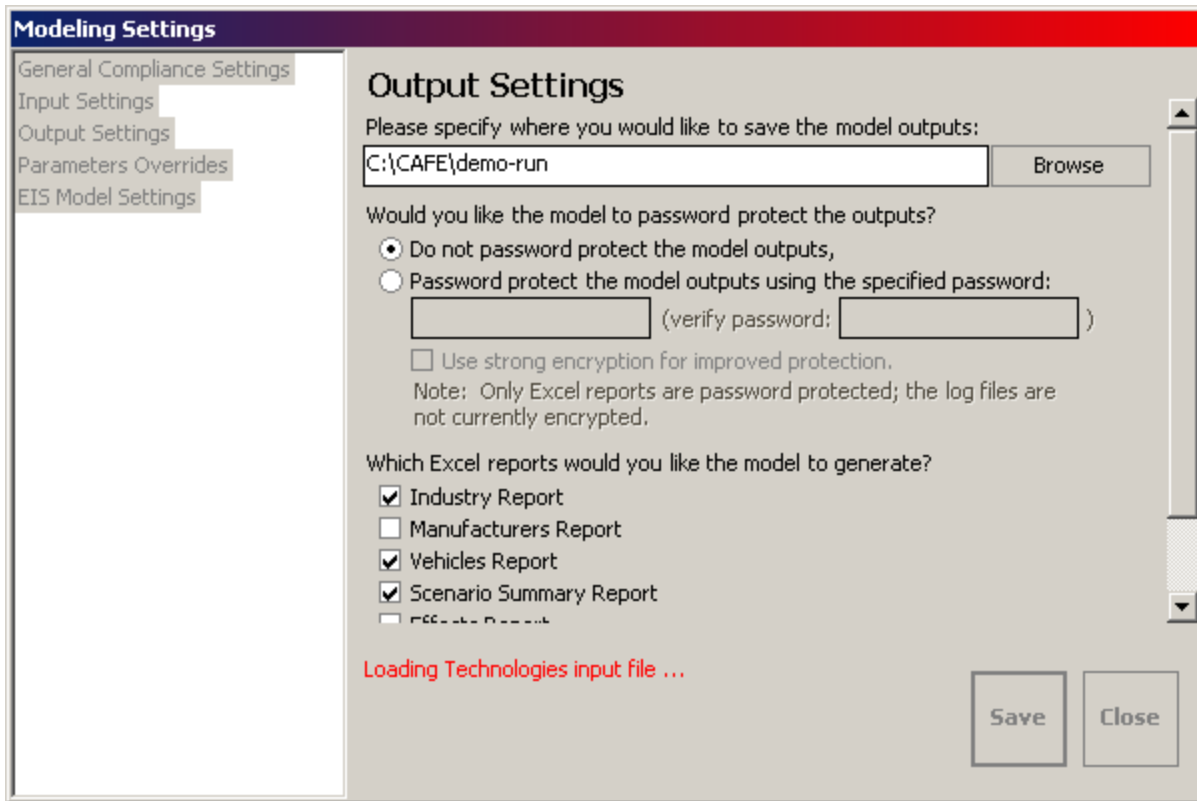
Figure 33. Save Modeling Settings

- Once loading completes, click the **Close** button to return the main **CAFE Model** window. A new Compliance Model session, titled "Session 1" has now been created (Figure 34).
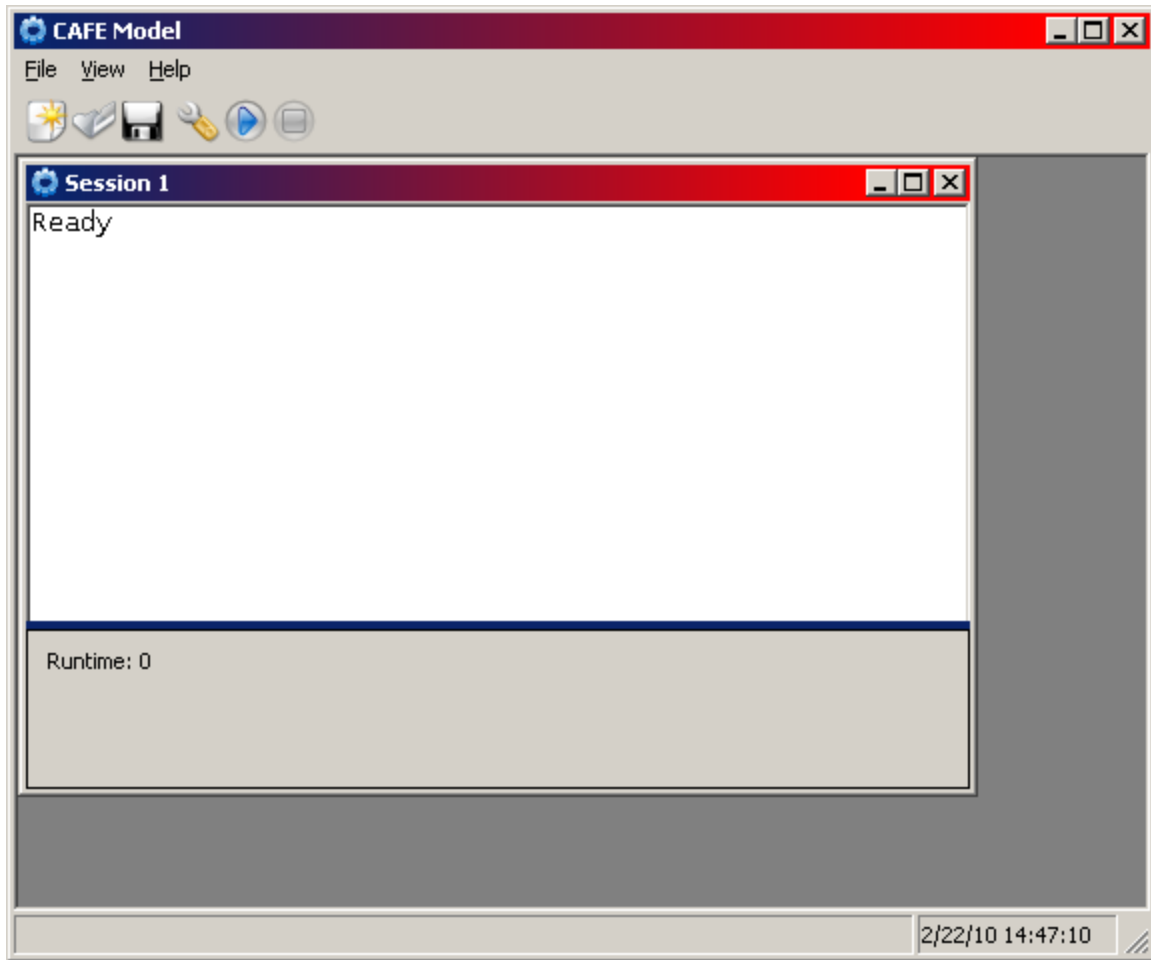
Figure 34. New Compliance Model Session Created

- Save the new session by selecting **File > Save Session As...**. Enter "demo.cmsd" in the dialog box that appears, and click the **Save** button (Figure 35).
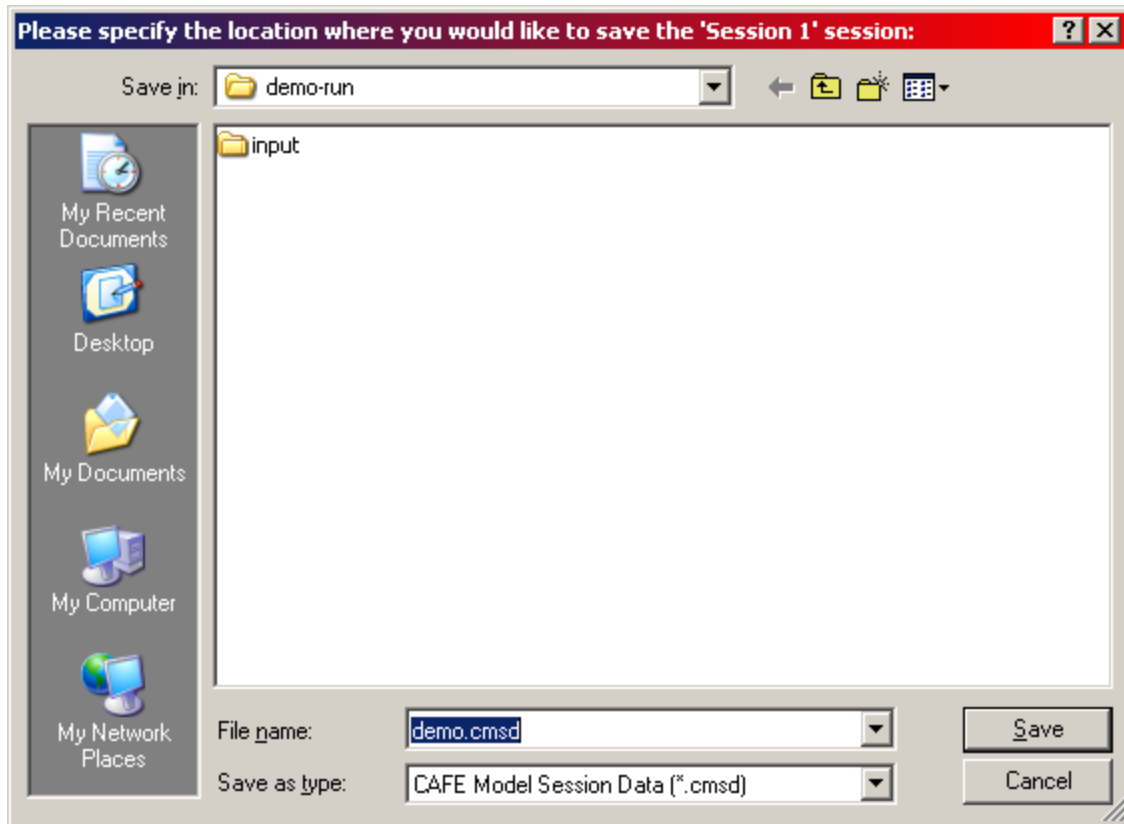
Figure 35. Save New Session

- After the session has been saved, notice the title of the session has changed to "demo" (Figure 36).
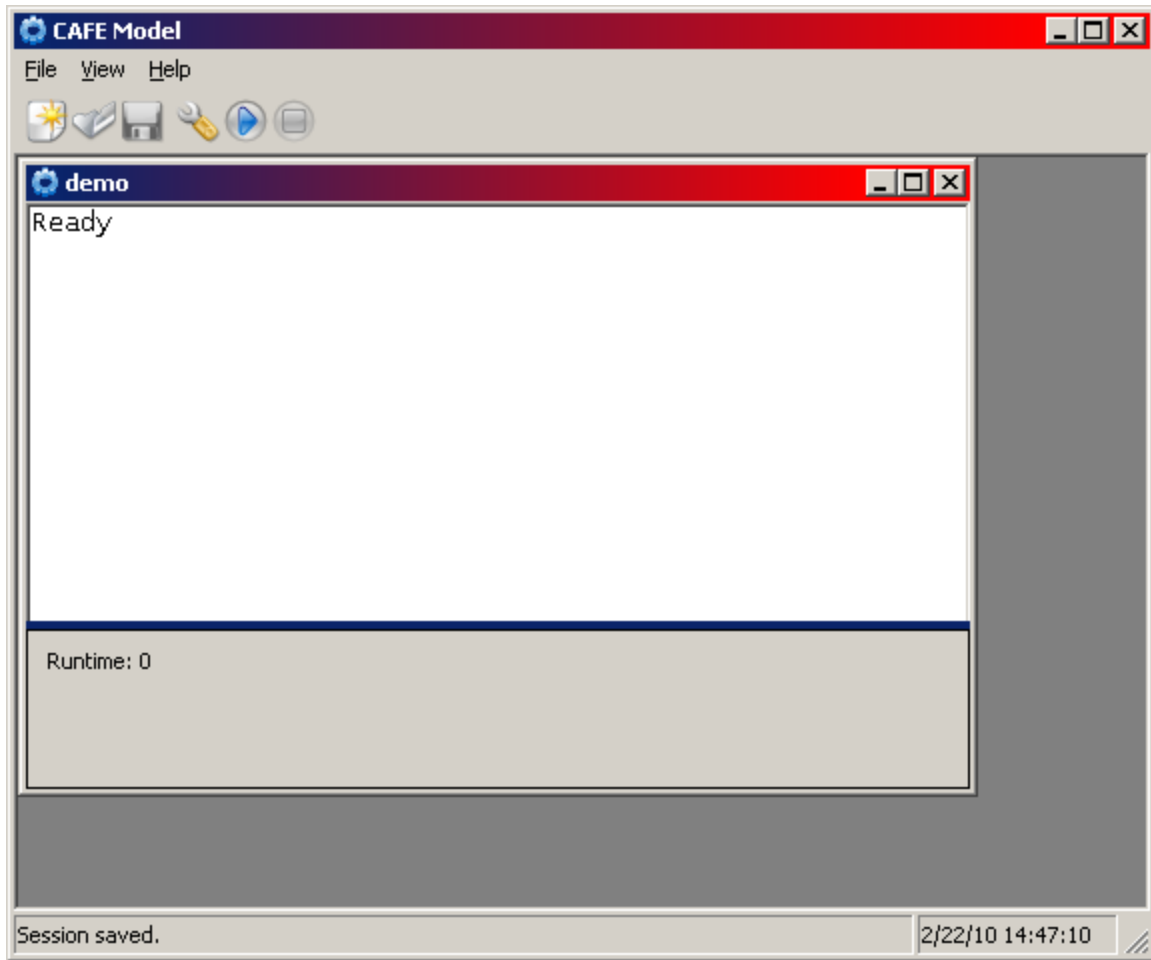
Figure 36. "demo" Session Saved

- Select **File > Start Modeling** to start the compliance modeling process. As the model runs, the progress of the Compliance Model is displayed in the session window (Figure 37).
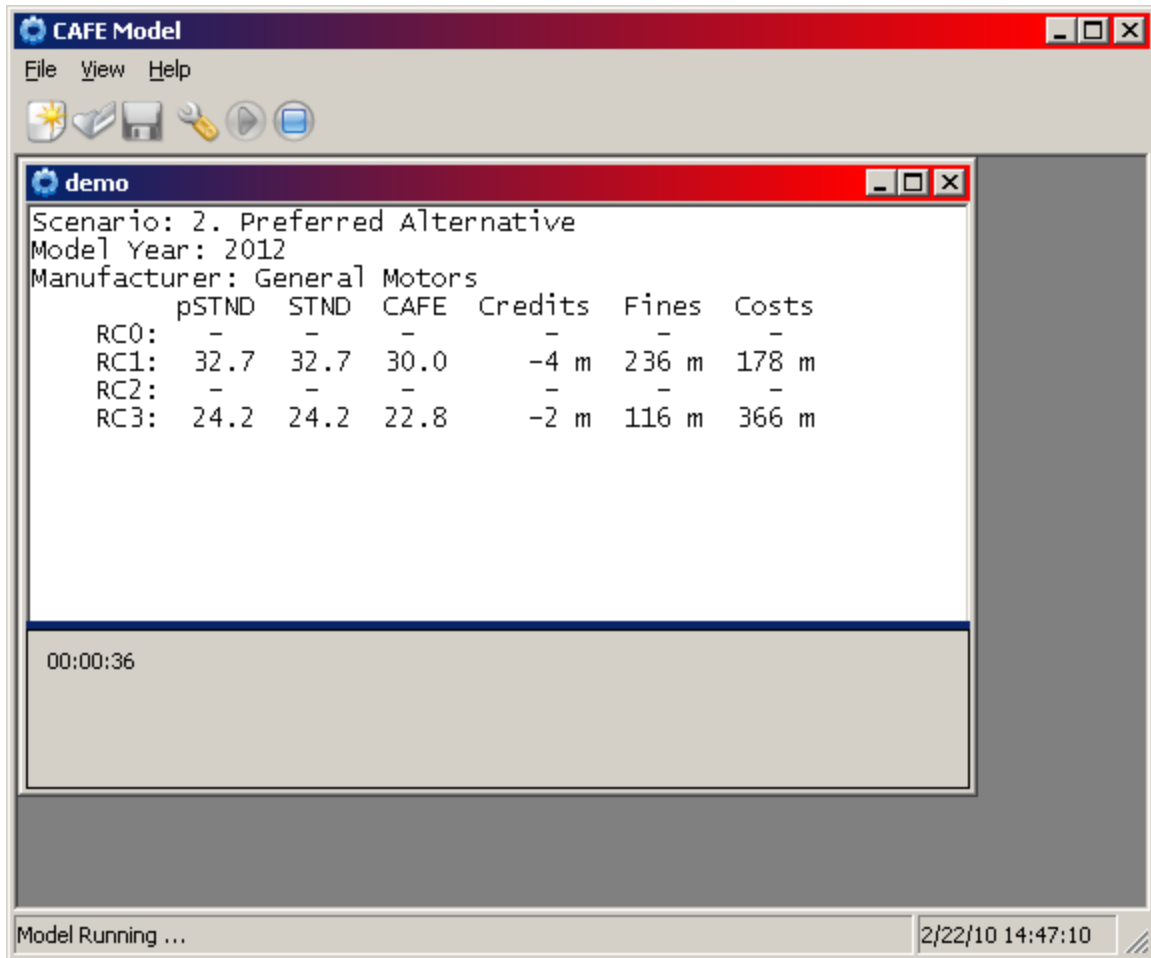
Figure 37. Modeling Progress from the Compliance Model

- Once the modeling process completes, the system will automatically switch to generating the modeling reports (Figure 38).

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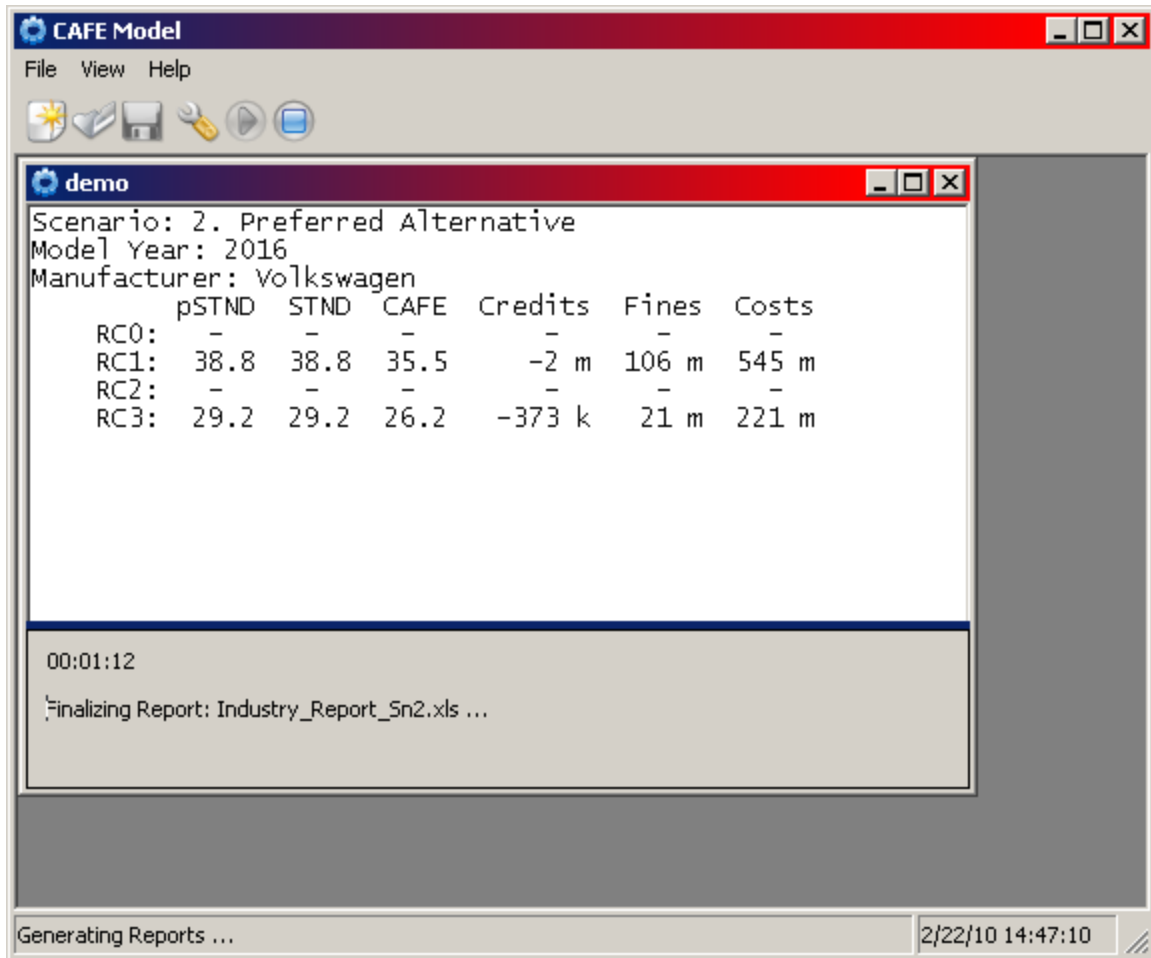
Figure 38. Generating Reports for the Compliance Model

- After modeling and reporting has completed, the "Reporting Completed!" message appears at the bottom of the main **CAFE Model** window (Figure 39).
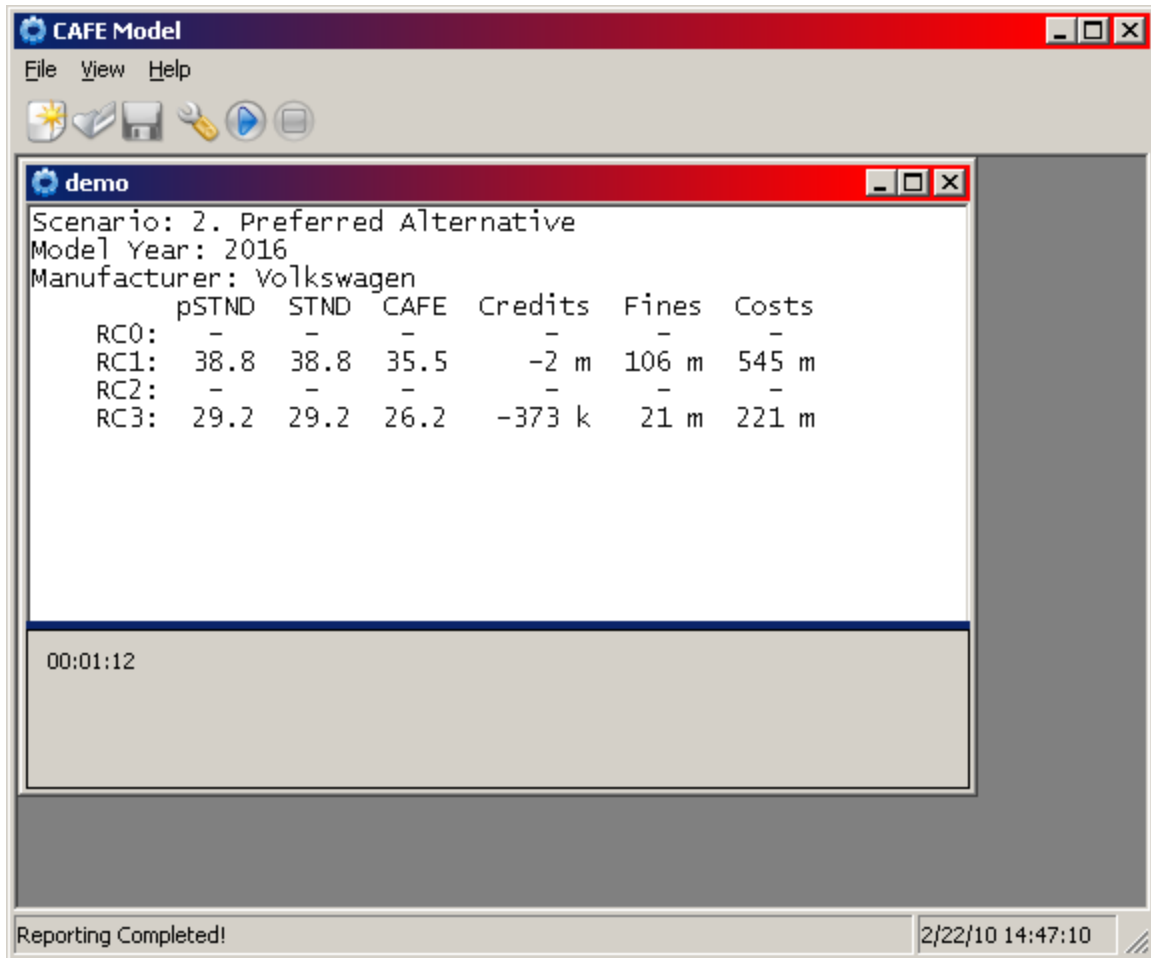
Figure 39. Compliance Model Completed

- Select **View > Output Location** to open Windows Explorer and browse to the location where model outputs for the "demo" session are saved.

- Exit the session by selecting **File > Close Session**.

- Exit the **CAFE Model** by selecting **File > Exit**, or proceed to the next example.

Appendix E.7.2   Example 2 – Configuring for Optimization Modeling

This example demonstrates how the take an existing session created in Example 1 – Configuring for Standard Compliance Modeling, and modify it to run the Optimization Model.

- Run the CAFE Model by clicking on the **CAFE Model** shortcut located on the desktop, or going to **Start > Programs > CAFE Model > CAFE Model**. Read through the **Warnings** dialog box, and then click the **OK** button.

- Select **File > Open Session** to open an existing modeling session. Select "demo.cmsd" in the dialog box that appears, and click the **Open** button (Figure 40).
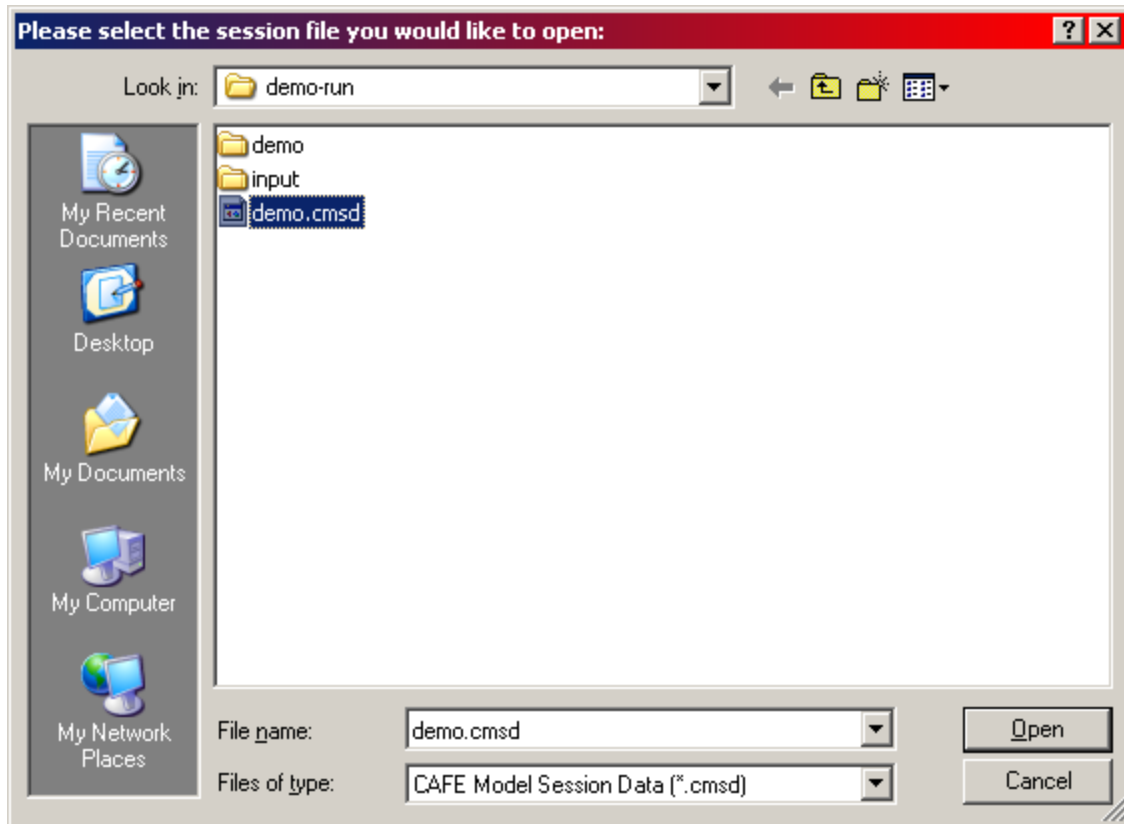
Figure 40. Open "demo" Session

- Once the session has been loaded, select **View > Modeling Settings** to bring up the **Modeling Settings** window. There select the Optimization Model as in Figure 41.

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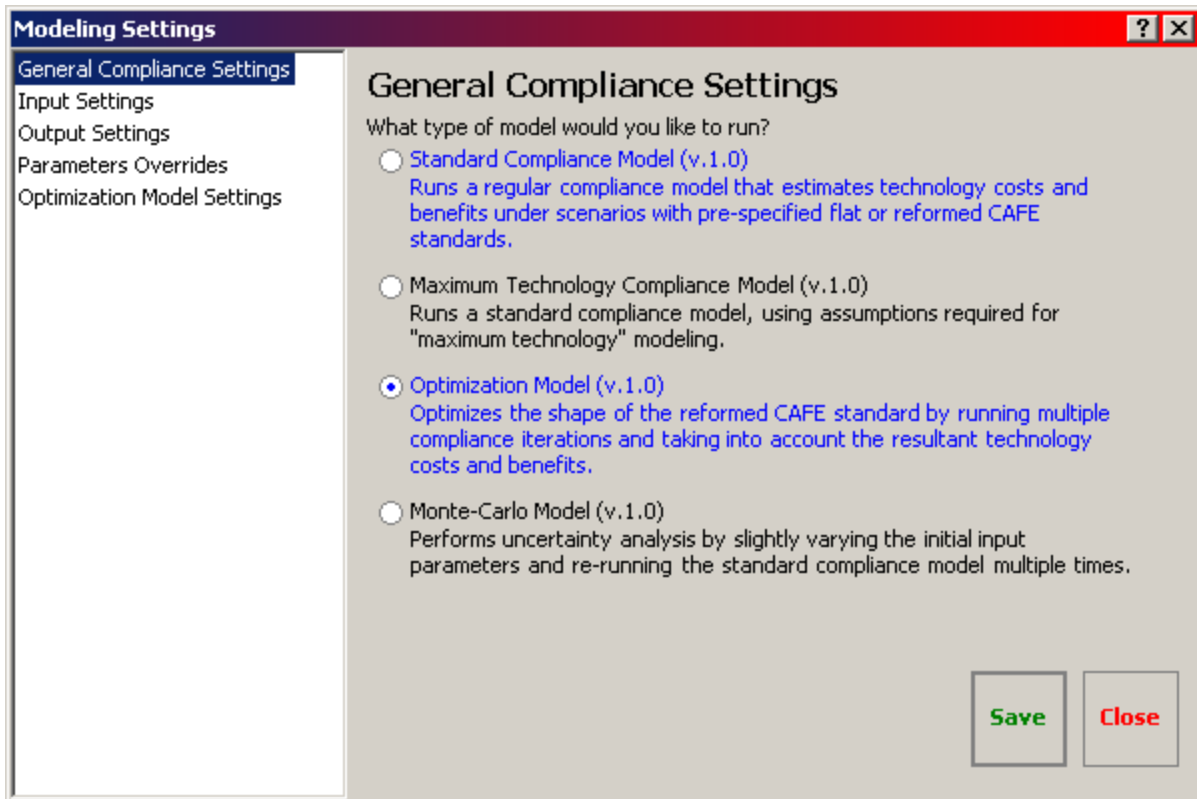
Figure 41. Select Optimization Model

- Under the **Input Settings** panel, select a market data file containing data for the light truck fleet only, as well as a scenarios file required for optimization modeling (Figure 42).
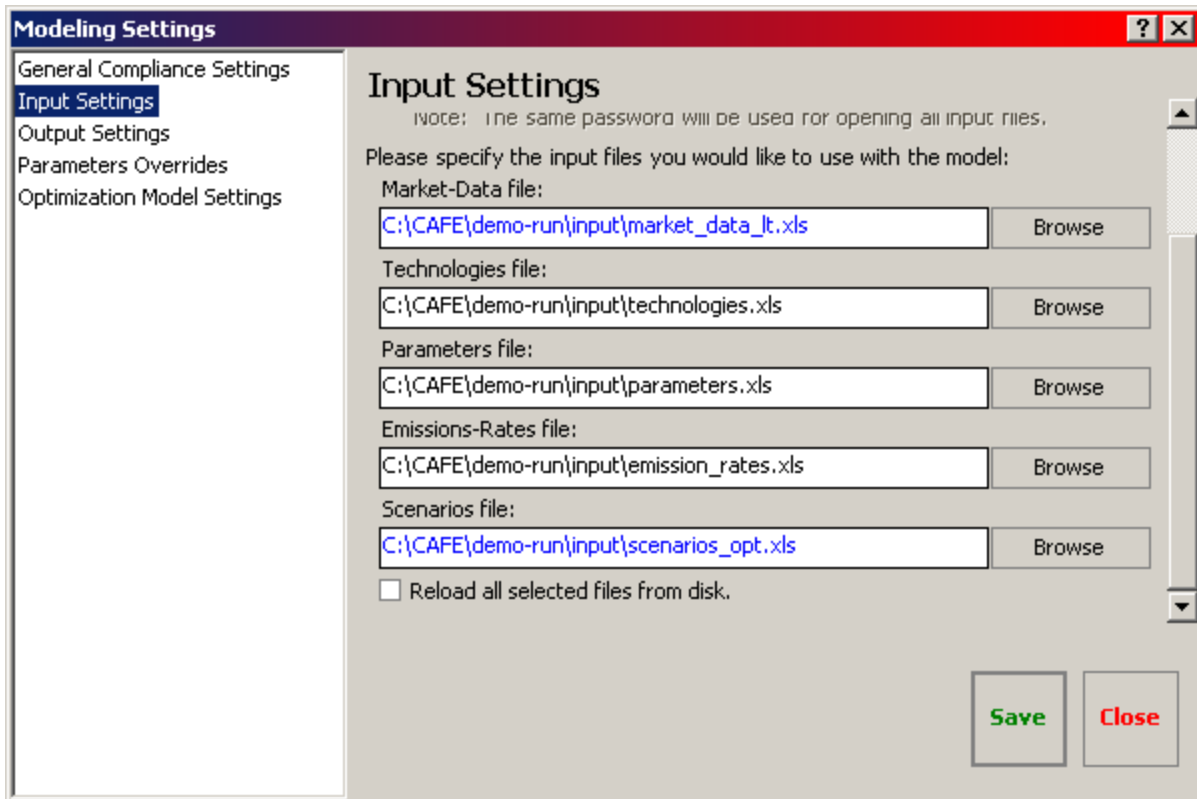
Figure 42. Select Scenarios File for Optimization

- On the **Output Settings** panel, deselect the industry, vehicles, and scenario summary reports, and select the optimized industry report (Figure 43).
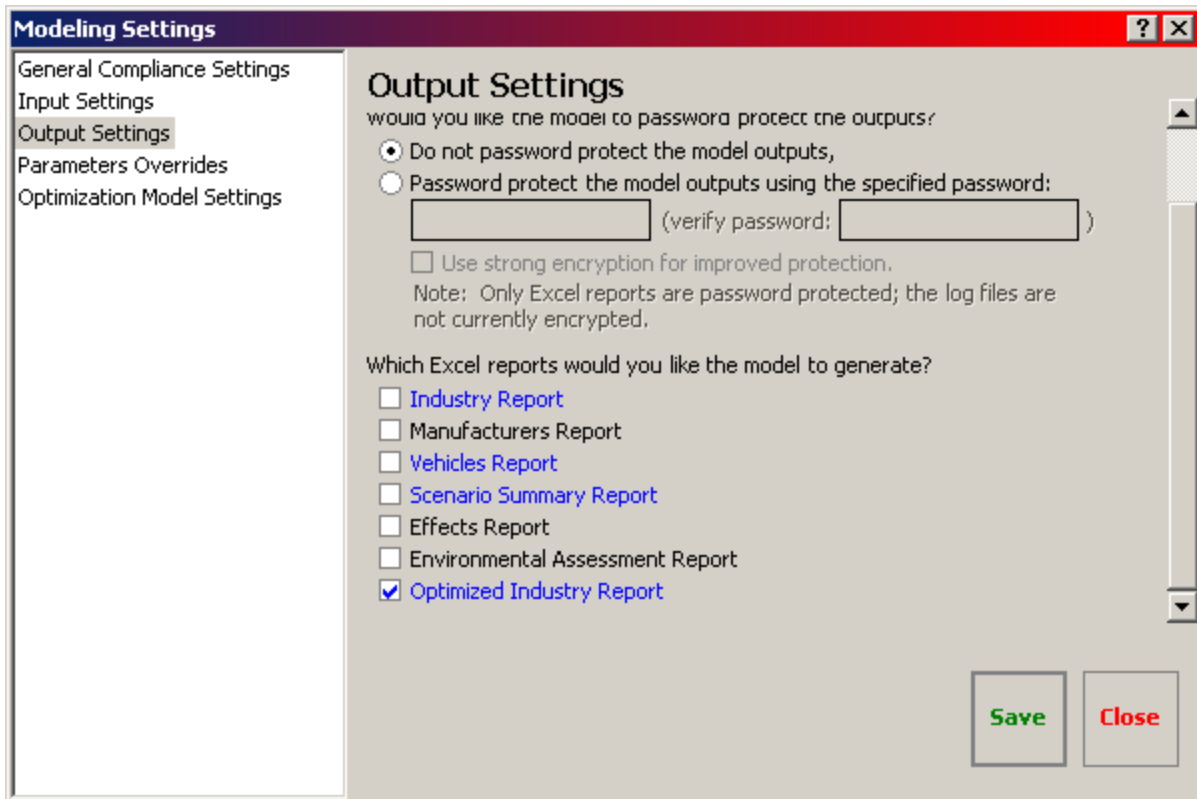
Figure 43. Select Reports for Optimization Modeling

- Use the **Optimization Model Settings** to configure the system for optimization modeling as specified in Figure 44.
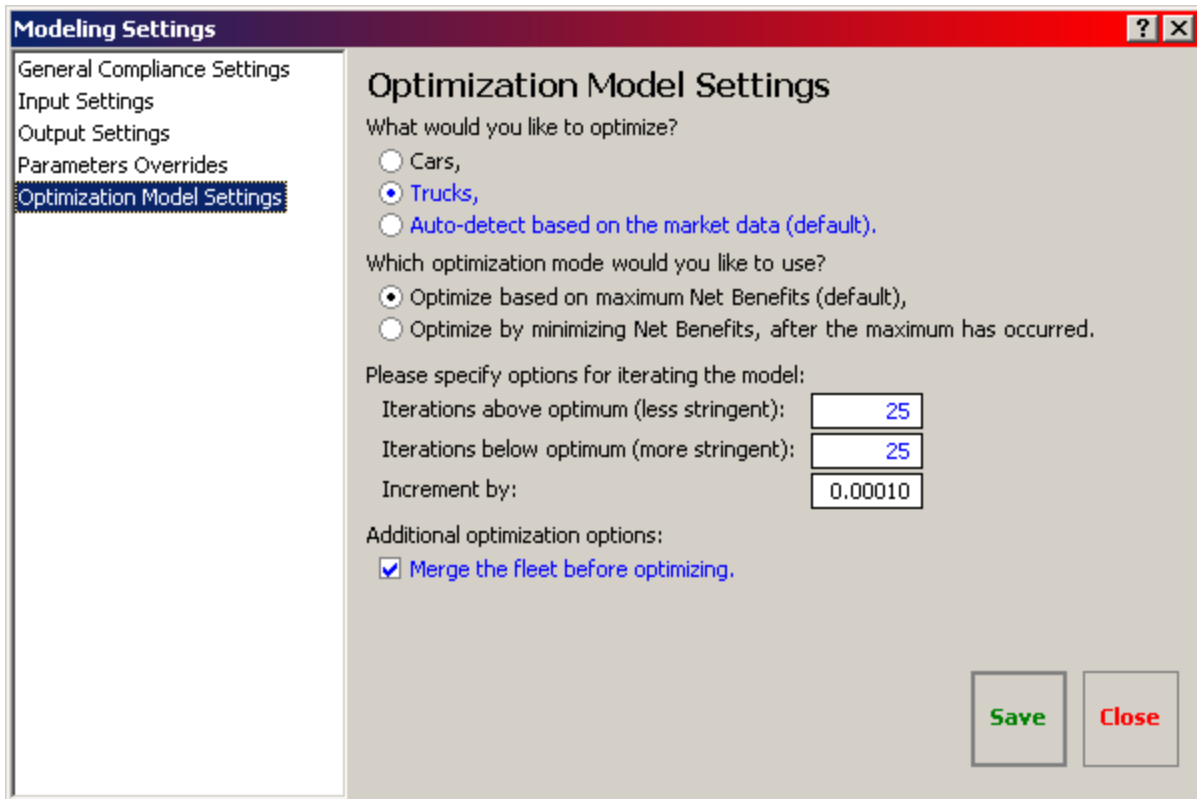
Figure 44. Configure Optimization Model Settings

- Click the **Save** button to save the updated modeling settings; then click **Close**, once saving completes.

- To prevent overwriting results from the "demo" session, select **File > Save Session As...** to save the modified session with a new name. For this example, the optimization session was saved as "demo-opt.cmsd" (Figure 45).
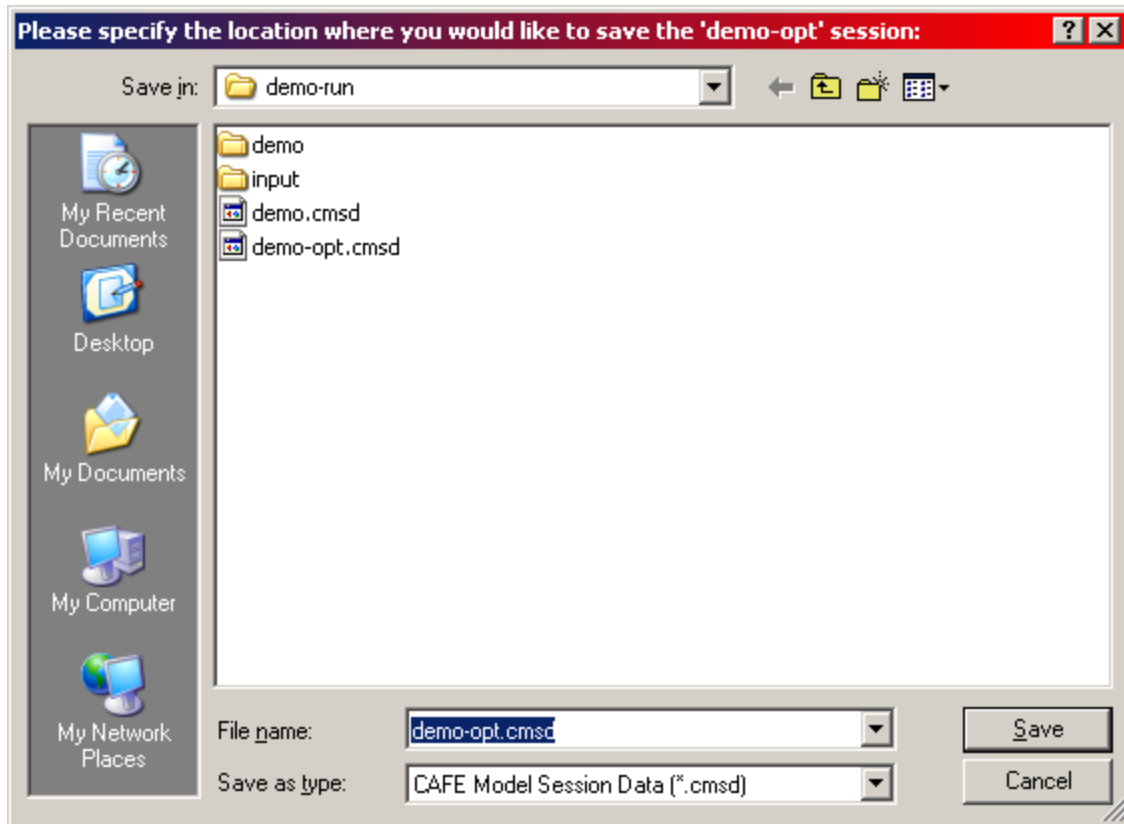
Figure 45. Save Modified Session

- Select **File > Start Modeling** to start the optimization modeling process. As the model runs, the progress of the Optimization Model is displayed in the session window (Figure 46).
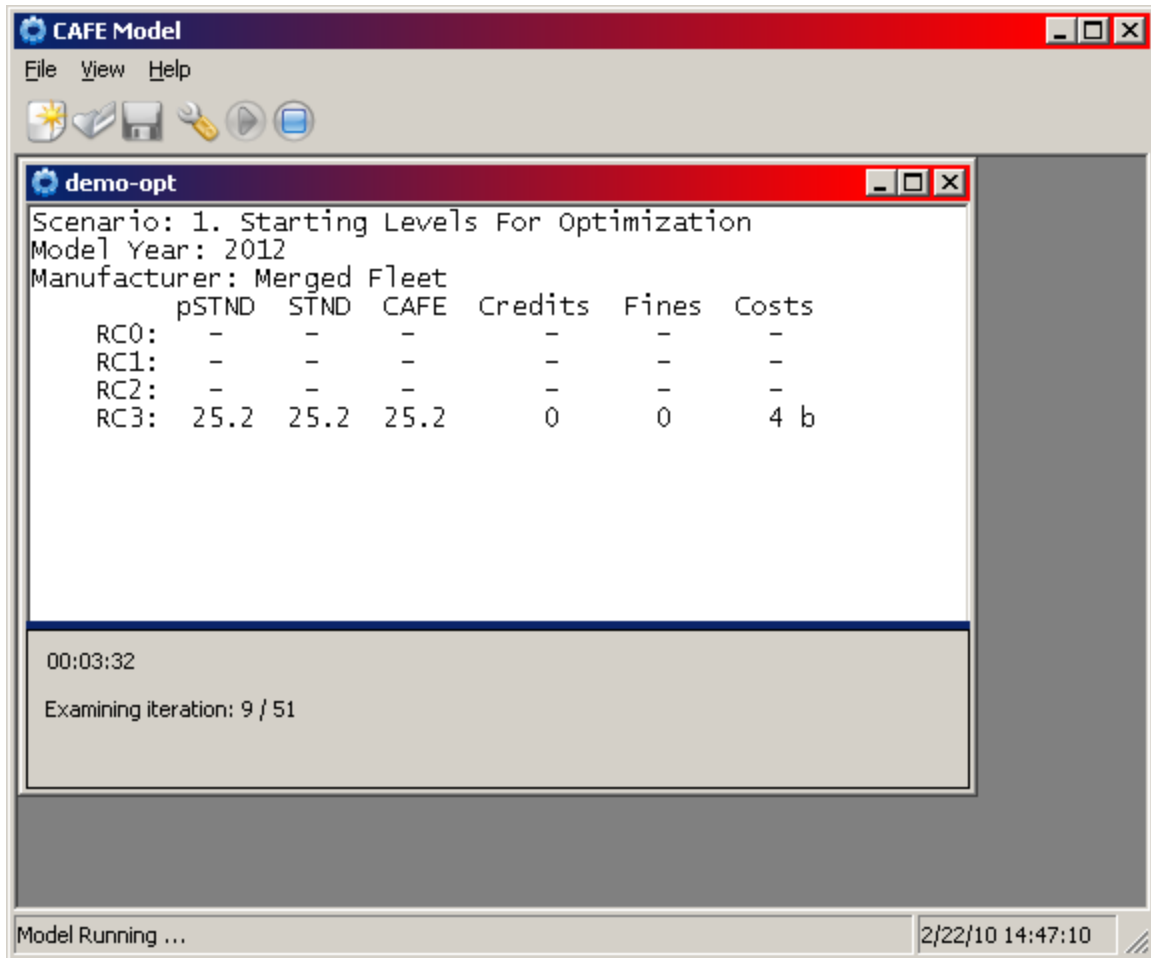
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Figure 46. Modeling Progress from the Optimization Model

- Once optimization modeling competes, the system will automatically begin generating modeling reports.

- After the "Reporting Completed!" message appears at the bottom of the main **CAFE Model** window, select **File > Exit** to exit the model.

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