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Corporate Average Fuel Economy Compliance and Effects Modeling System Documentation

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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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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)

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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)

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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)

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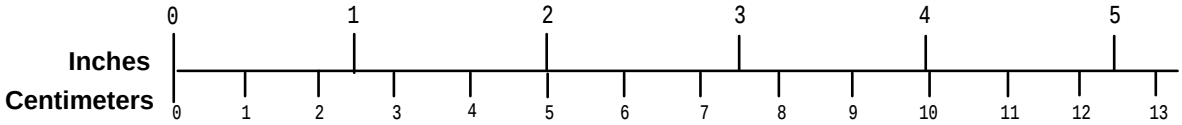

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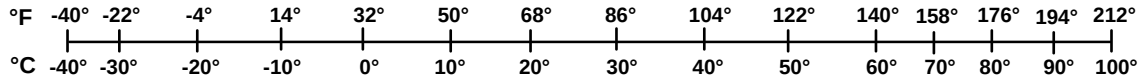

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PREFACE

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.

This report documents the design and function of the CAFE Compliance and Effects Modeling System as of October 30, 2008, specifies the content, structure, and meaning of inputs and outputs, and provides instructions for the installation and use of the modeling system.

The authors of this report are John Van Schalkwyk, Walter Gazda, Kevin Green, Donald Pickrell, and Mark Shaulov.

The authors acknowledge the technical contributions of individuals who have been involved in guiding recent changes to the modeling system, including Ryan Harrington and Josh Templeton of the Volpe Center, Peter Feather, Donna Glassbrenner, Phil Gorney, Ken Katz, and Scott Yon of NHTSA, Arthur Rypinski of the Office of the Secretary of the Department of Transportation, and David Boggs, Anrico Casadei, Scott Ellsworth, and Sandy Stojkovski of Ricardo, Inc. The authors further acknowledge former Volpe Center staff who participated in the development of earlier versions of the modeling system, including Gregory Ayres, Kristina Lopez-Bernal, and Kenneth William.

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Abbreviations

a.....vehicle vintage
$\boldsymbol{A}_C$ .....values of attribute (*e.g.*, footprint) of vehicles in regulatory class C
AMT.....automatically-shifted 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
$FCReduction_{0,1\ldots}$ .....fuel consumption reduction from applied technologies 0, 1, …
$\boldsymbol{FE}_C$ .....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
$\mathbf{N}_C$.....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, 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.

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 (*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 that generally do not pay fines, thus forcing the manufacturer to add additional technology. At this stage, the system assigns an incurred technology cost and updated fuel economy to each vehicle model, as well as any civil penalties incurred by each manufacturer.

This point marks the system's transition between compliance simulation and effects calculations. At the conclusion of the compliance simulation for a given model year, the system contains a new fleet of vehicles with new prices, 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 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 D.4). 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 2009 Final Rule (FR) regarding CAFE standards for passenger cars and light trucks produced for sale in the United States in model years 2011.[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

[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.

Class	Description
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) • Continuously Variable Valve Lift (CVVL) 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) Higher Voltage/Improved Alternator (HVIA) Belt Mounted Integrated Starter Generator (BISG)
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)	Material Substitution 1% (MS1) Material Substitution 2% (MS2) Material Substitution 5% (MS5)

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

Technology Group	Group Members
Hybrid Technology Group (HEV)	Power Split Hybrid (PSHEV) 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)

As shown in Appendix D.4, 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] (retail price equivalent in 2007 dollars)
Cost-Upper	maximum added cost (retail price equivalent 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.

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

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. material substitution technology only applies to vehicles over 5,000 pounds curb weight), 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:

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

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

2.2.2.5 Technology Synergies

Technology synergies exist when the combination of two technologies yields a fuel consumption reduction which differs from what would be derived directly from equation (1) above. The synergy can be positive (increased reduction of fuel consumption) or negative (decreased reduction of fuel consumption). Synergy relationships within a technology group are accounted for within the fuel consumption reduction factors for the technologies within that group.

Synergy relationships between technology groups are captured in the 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 factor is added to the fuel consumption reduction value. Although 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).

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

2.2.2.6 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. 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 2009 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 (2), the formula used for learning cost based on time is shown in equation (3).

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

$$Cost = CostBeforeLearning * (1 - LearningRate)^{(year - StartYear)} \tag{3}$$

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 C.

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.

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

[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.

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 (Appendix D.4). 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) engines, single overhead cam engines (SOHC) and for engines with dual overhead cams (DOHC).

[7] These overrides, described in Appendix C.2 on page 57, provide a means of accounting for engineering and other issues not otherwise represented by input data or the overall system.

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 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.

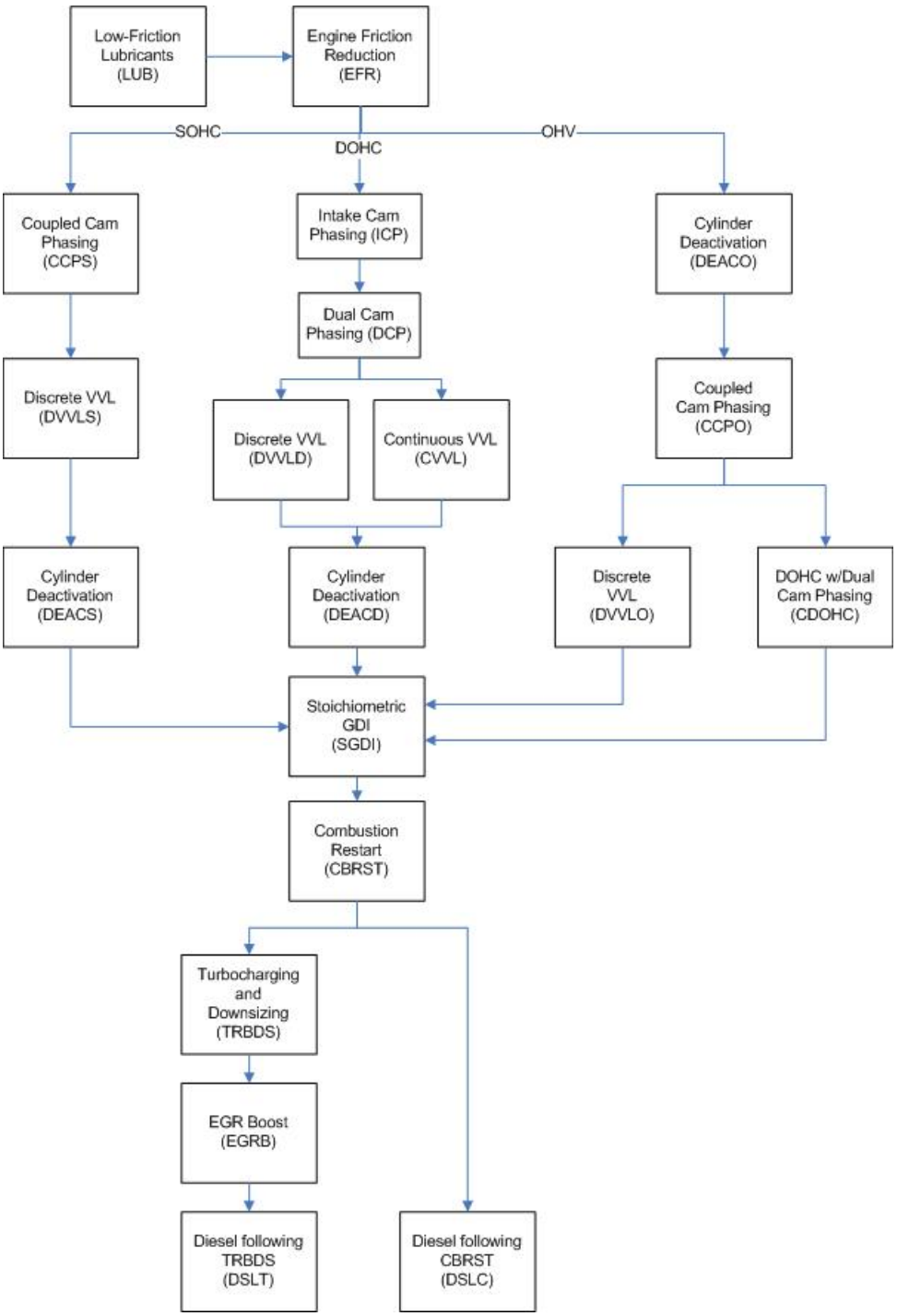

Figure 2. Engine Technology Group Technology Sequence

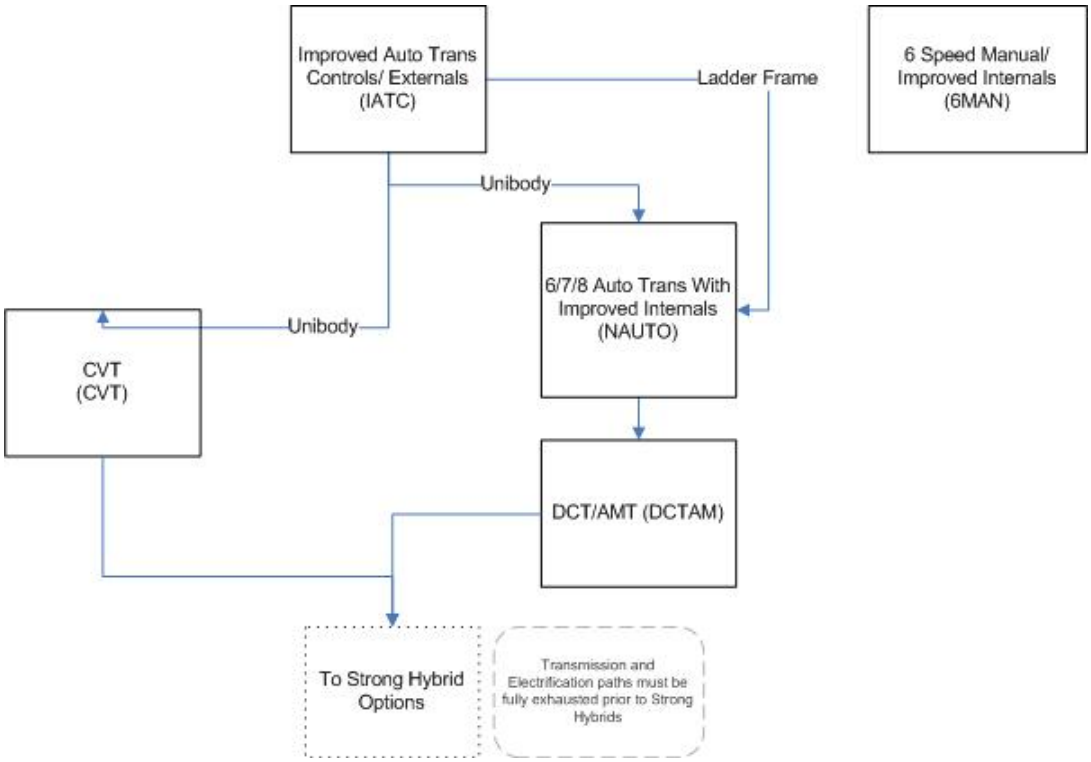

Figure 3. Transmission Technology Group Technology Sequence

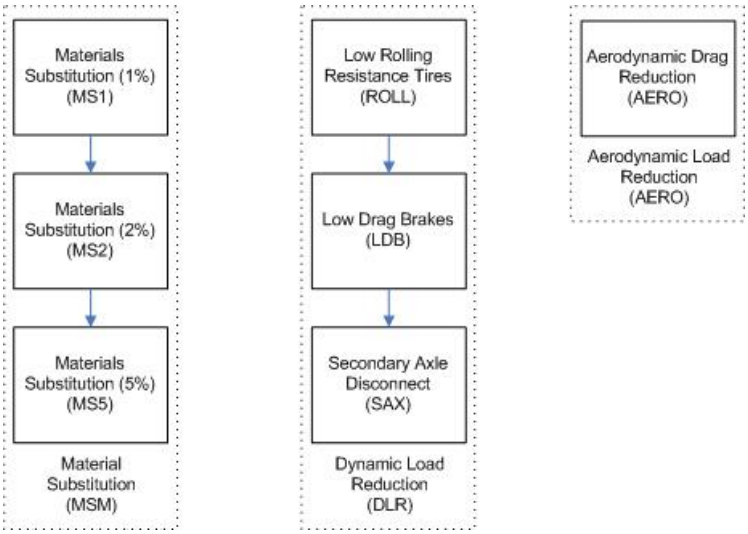

Figure 4. Other Vehicle Technology Sequencing.

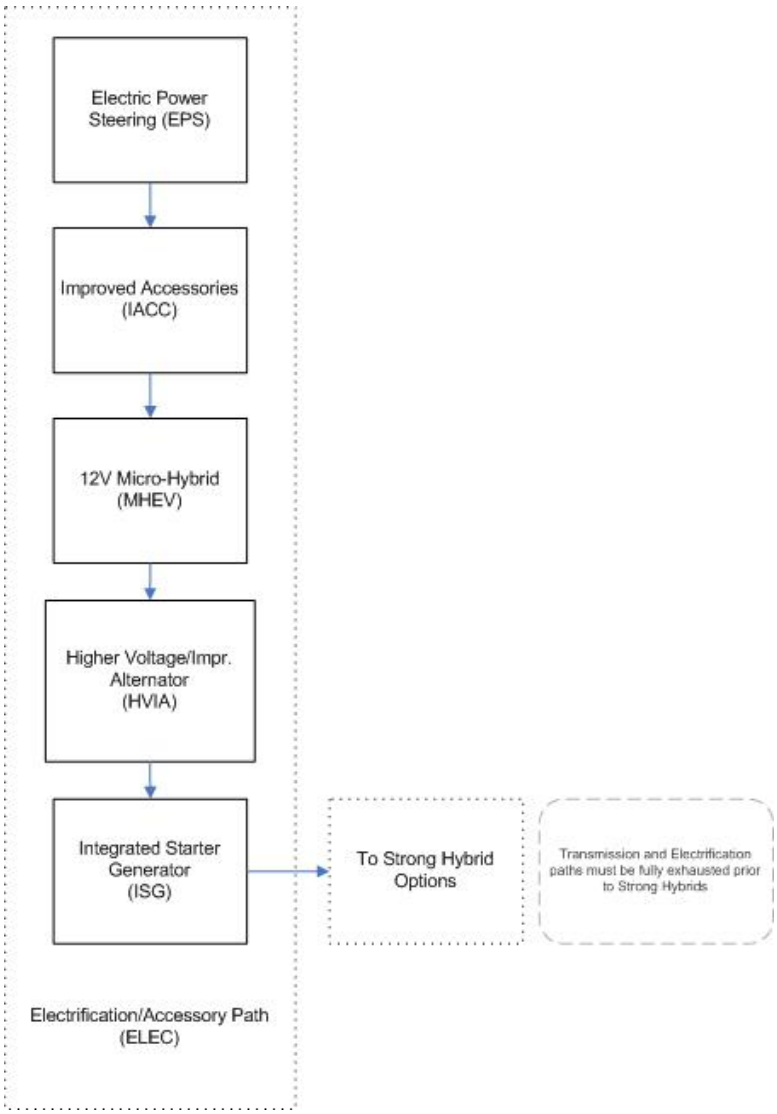

Figure 5. Electrical Accessory Technology Group Sequencing

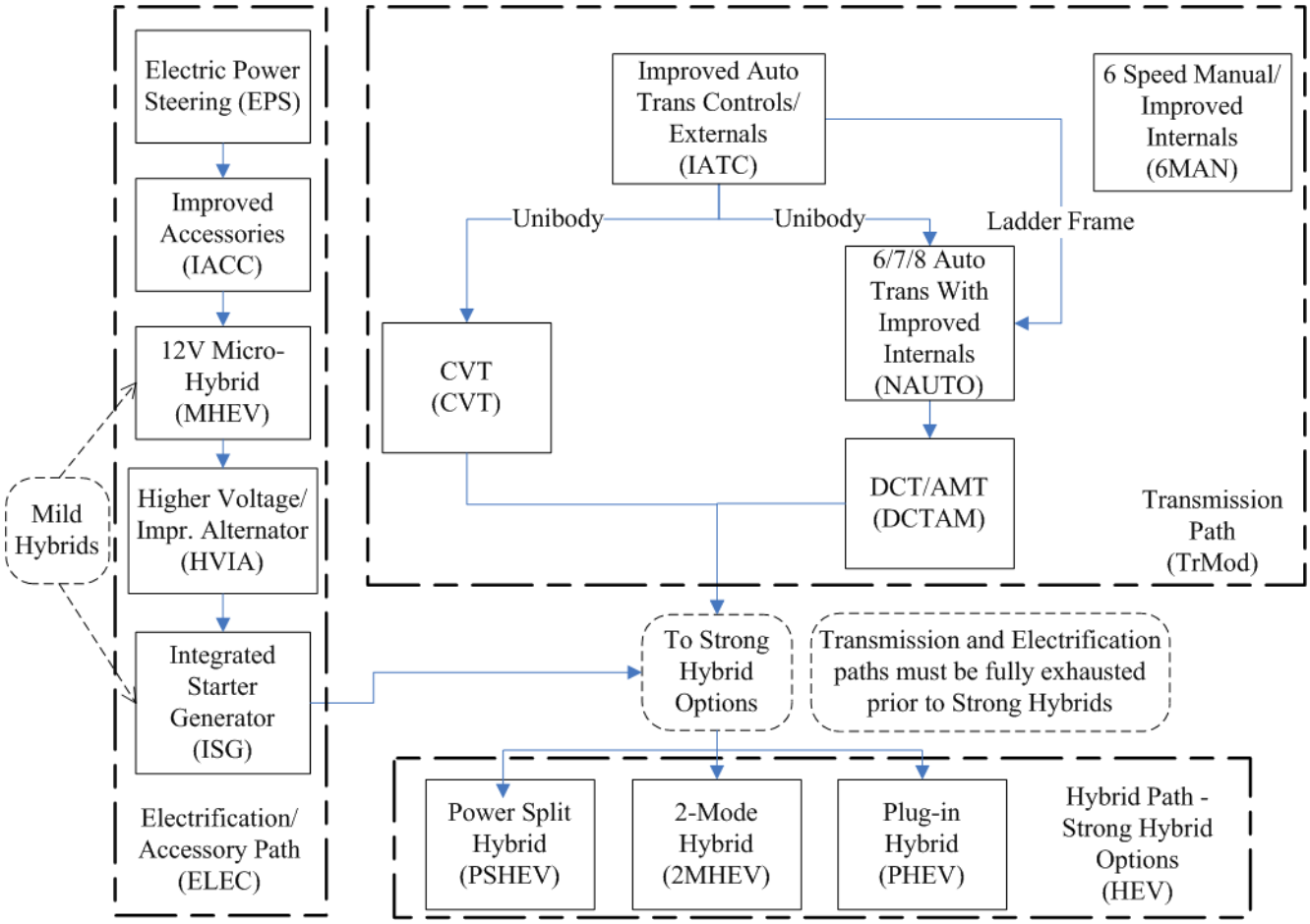

Figure 6. Strong Hybrid Electric Vehicle Options

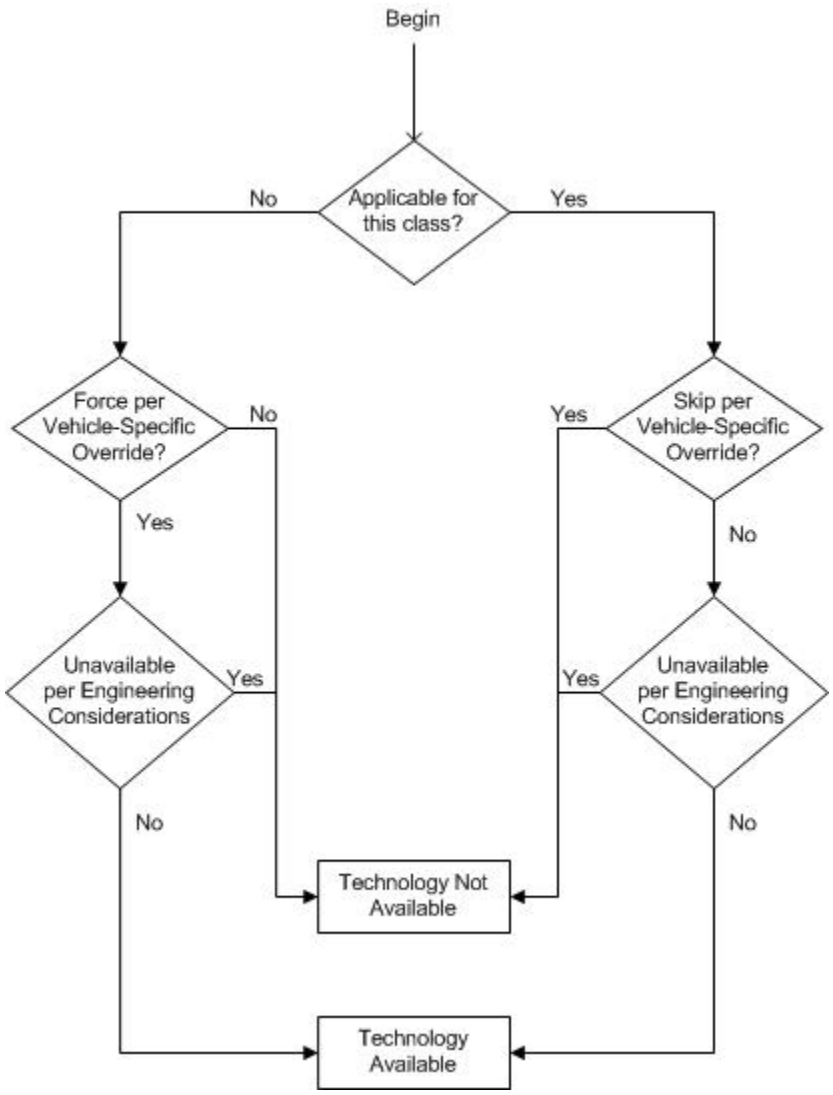

Figure 7. Technology Applicability Determination

2.2.3 Compliance Simulation Loop

If a given technology is still considered applicable after considering any overrides, the algorithm again reevaluates 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.
Material Substitution	Do not apply to vehicles with curb weights below 5,000 pounds.[8]

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 willing 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, the compliance simulation algorithm concludes.

[8] This constraint it is not an inherent engineering constraint such as the constraint preventing SGDI from being applied to diesel engines. It is based on a judgment by NHTSA that vehicle safety may be negatively impacted if material substitution is applied to these vehicles. In the current version of the modeling system, this constraint can be changed through reprogramming the model. Future versions may offer the ability to control this constraint through an input to the model.

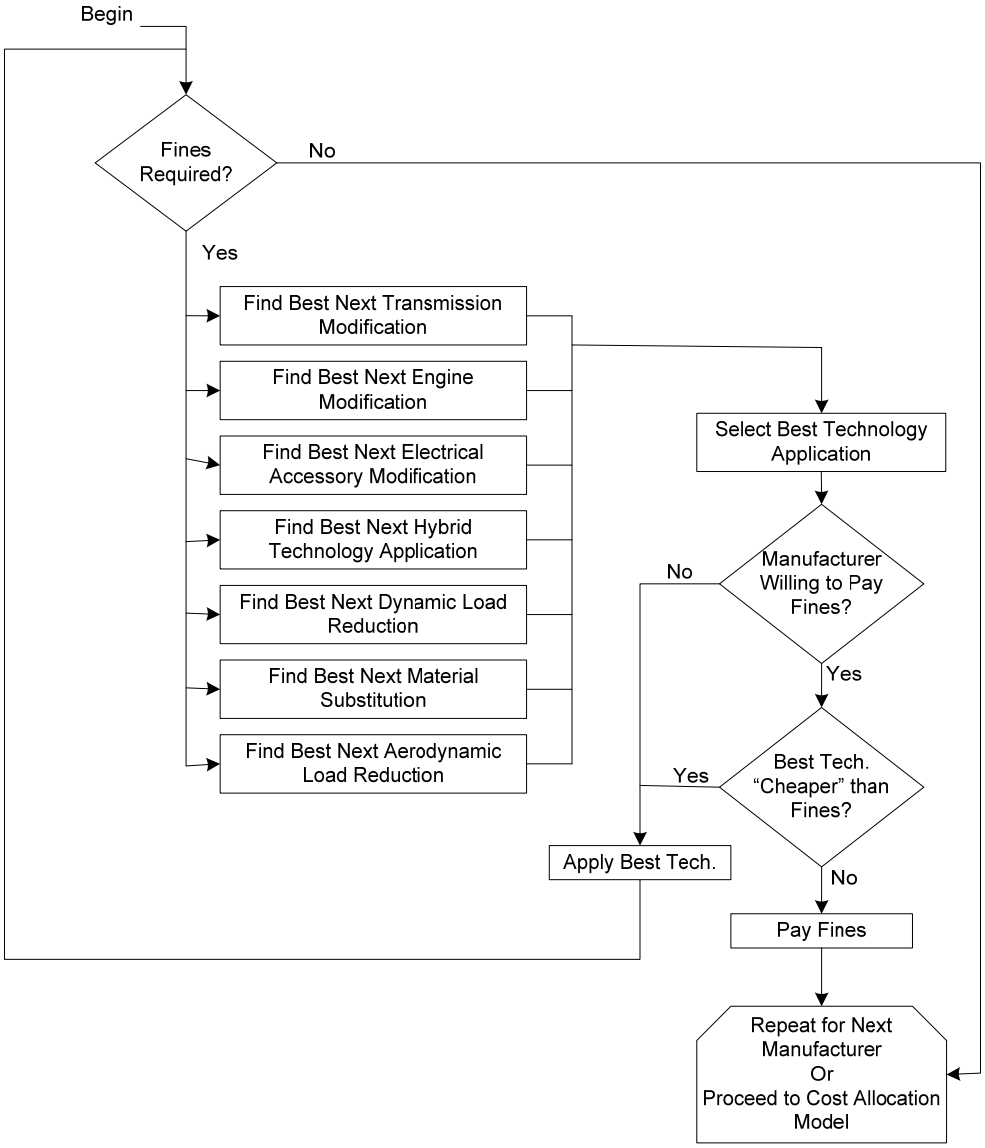

Figure 8. Compliance Simulation Algorithm

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.[9] The effective cost is used for

[9] 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:

$$COST_{eff} = \frac{\Delta TECHCOST + \Delta FINE - VALUE_{FUEL}}{N_j} \tag{4}$$

where $\Delta TECHCOST$ is simply the product of the unit cost of the technology and the total sales (Nj) of the affected cohort of vehicles (j). The value of the reduction in fuel consumption achieved by applying the technology in question to all vehicles i in cohort j is calculated as follows:[10]

$$VALUE_{FUEL} = \sum_{i \in j} \left[N_i \sum_{v=0}^{v=PB} \frac{SURV_v MI_v FUELPRICE_{MY+v}}{(1-gap)(1+r)^{v+0.5}} \left(\frac{1}{FE_i} - \frac{1}{FE_i'} \right) \right] \tag{5}$$

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 (4), $\Delta FINE$ is the change in total CAFE fines (*i.e.*, accounting for all regulatory classes in the current CAFE scenario and model year). Typically, $\Delta FINE$ is negative because applying a technology would increase CAFE.[11] $\Delta FINE$ is calculated by evaluating the following before and after the pending technology application, and taking the difference between the results:

$$FINE = -k_F \sum_C \mathrm{MIN}\left(CREDIT_C, 0\right) \tag{6}$$

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

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:

[10] 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.

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

$$CREDIT_C = N_C\left[\mathrm{STD}_C\left(\mathbf{N}_C,\mathbf{A}_C\right) - \mathrm{CAFE}_C\left(\mathbf{N}_C,\mathbf{FE}_C\right)\right] \quad (7)$$

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

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 (4), (5), (6) and (7), irrespective of the manufacturer's willingness to pay fines.

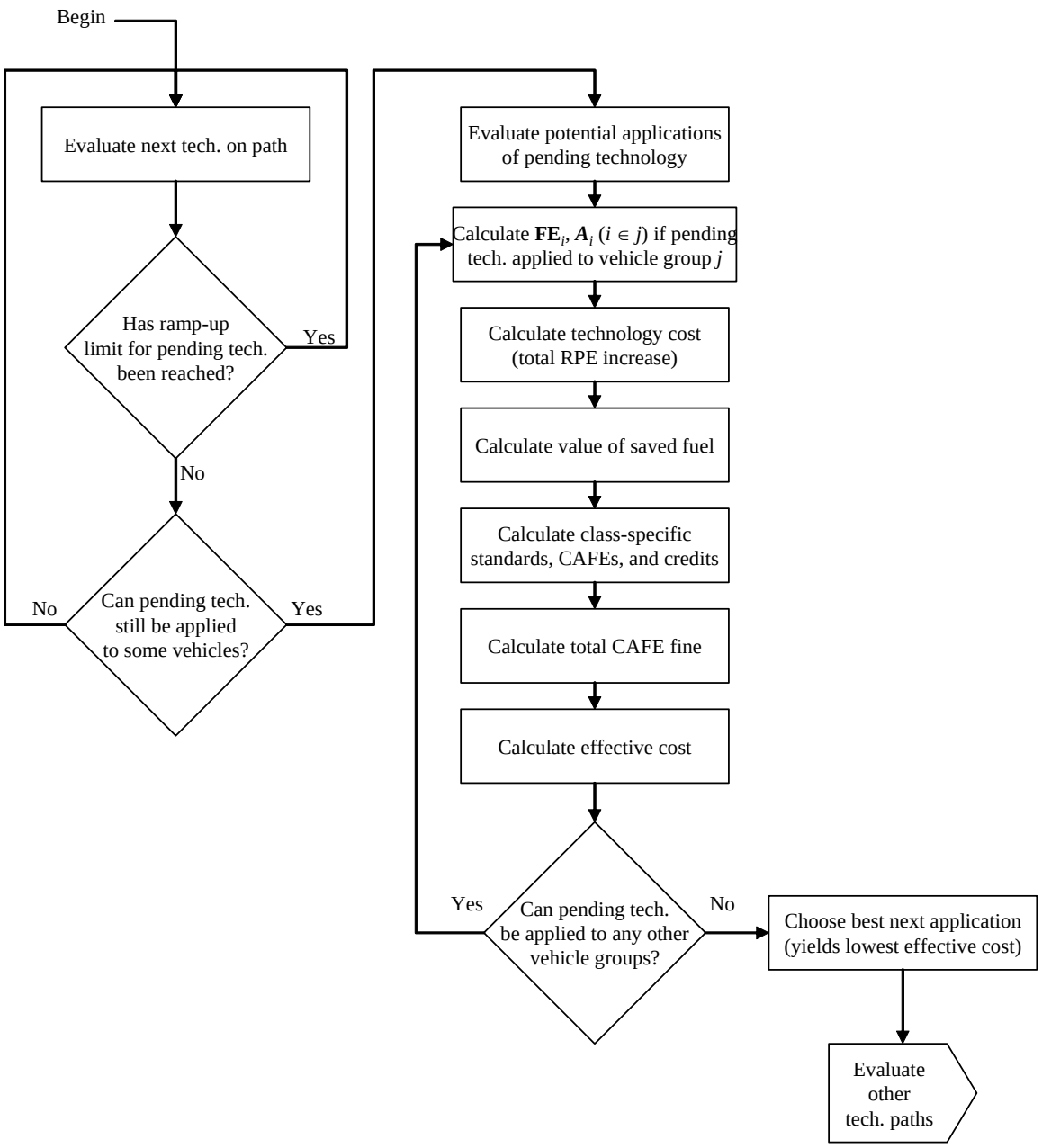

Figure 9. Determination of "Best Next" Technology Application

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.[12] 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:

$$n_{k,MY} = N_{MY} P_{k,MY} \tag{8}$$

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

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

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:

$$n_{k,MY,t} = n_{k,MY} s_{k,a} \quad (9)$$

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 $a = t - MY$.[13] 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:

$$M_{k,MY,t} = n_{k,MY,t} m_{k,a} \quad (10)$$

where $m_{k,,a}$ is the average number of miles that a surviving vehicle of model k is driven when it has reached age $a = t - MY$. 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.[14] This increase in the use of vehicles with increased fuel economy is referred to as the "rebound effect" in vehicle use.

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[13] 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.

[14] 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.

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

$$\frac{\Delta m_{k,MY,t,CAFE}}{m_{k,MY,t}} = \varepsilon_{cpm}\left[\frac{\dfrac{f_t}{mpg_{k,CAFE}} - \dfrac{f_t}{mpg_{k,plan}}}{\dfrac{f_t}{mpg_{k,plan}}}\right] \qquad (11)$$

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 (11) represents the proportional reduction in fuel cost per mile driven resulting from the improvement in fuel economy.[15]

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:

$$\Delta m_{k,MY,t,CAFE} = \varepsilon_{cpm}\left(\frac{mpg_{k,MY,plan}}{mpg_{k,MY,CAFE}} - 1\right) m_{k,MY,t} \qquad (12)$$

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:

$$\Delta M_{k,MY,t,CAFE} = n_{k,MY,t}\Delta m_{k,MY,t,CAFE} \qquad (13)$$

where $n_{k,MY,t}$ is given by equation (9).

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

[15] 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.

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.

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:

$$\Delta M_{k,a,t,CAFE1} - \Delta M_{k,a,t,CAFE0} = n_{k,a,t}\left(\Delta m_{k,a,t,CAFE1} - \Delta m_{k,a,t,CAFE0}\right) \quad (14)$$

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:

$$g_{k,MY,t} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY}\left(1 - gap\right)} \quad (15)$$

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.[16]

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

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

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

For any vehicle model whose fuel efficiency its manufacturer elects to increase as part of its strategy to comply with a CAFE standard (including an extension to future model years of the prevailing standard), the appropriate form of equation (16) is:

$$g_{k,MY,t,CAFE} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} \tag{17}$$

or, equivalently:

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

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

$$G_{t,CAFE1} = \sum_{MY} \sum_{k} \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0} \right) \tag{19}$$

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:

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

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:

$$PV\left(G_{MY,CAFE1}\right) = \sum_{t} \sum_{k} \left(\frac{g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}}{(1+d)^{t-MY}} \right) \tag{21}$$

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.[17] 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.[18]

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:

$$C^{tp}_{k,MY,t,CAFE1} = \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right) c_f \, (MW_{CO2}/MW_C) \qquad (22)$$

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

[17] 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.

[18] 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).

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, 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:

$$C_{k,MY,t}^{tot} = g_{k,MY,t}\left(c_f + c_r + c_d\right) \tag{23}$$

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:

$$C_{k,MY,t,CAFE1}^{tot} = \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right)\left(c_f + r \cdot c_r + c_d\right) \tag{24}$$

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:

$$E^{tp}_{i,k,MY,t} = \left(M_{k,MY,t} - \Delta M_{k,MY,t}\right) e_{i,k,a} \qquad (25)$$

where ($M_{k,MY,t} + \Delta M_{k,MY,t}$) is given by (25), 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.[19] 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:

$$E^{up}_{i,k,MY,t} = g_{k,MY,t}\left(r \cdot e_{i,r} - e_{i,d}\right) \qquad (26)$$

where $g_{k,MY,t}$ is calculated from (26), 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:

$$E^{tot}_{i,k,MY,t} = E^{tp}_{i,k,MY,t} + E^{up}_{i,k,MY,t} \qquad (27)$$

In turn, the effect on criteria pollutant emissions of a proposed increase to a standard $CAFE_1$ a baseline standard of $CAFE_0$ is

$$\begin{aligned} E^{tot}_{i,k,MY,t,CAFE1} = &\left(\Delta M_{k,MY,t,CAFE1} - \Delta M_{k,MY,t,CAFE0}\right) e_{i,k,MY,t} \\ &+ \left(g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}\right)\left(r \cdot e_{i,r} + e_{i,d}\right) \end{aligned} \qquad (28)$$

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

[19] 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.

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

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.[20] 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 components: (1) higher costs for oil imports resulting from the combined effect of U.S.

[20] 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.

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 Installation

The CAFE Compliance and Effects Modeling System runs on IBM-compatible computers using the Microsoft® Windows operating system. A processor speed of at least 1 GHz is required, with 2 GHz and above highly recommended, as is physical RAM of at least 1 GB.[21] The software has been developed on computers using Windows XP, but may operate properly on machines using older versions of Windows (*e.g.*, Windows 2000), or newer versions (*e.g.*, Windows Vista), 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 present. 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 may be used with such versions.

The software uses the Microsoft® .NET Framework. If the Framework is not already present, it must be installed. Instructions are available on the Internet at http://msdn.microsoft.com/netframework/downloads/framework1_1/.[22]

The software also used the Microsoft® Visual J# .NET Redistributable Package 1.1, which can be obtained on the Internet at http://msdn2.microsoft.com/en-us/vjsharp/bb188598.aspx.[23]

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

Based on the characteristics of machines used in the development of this software, Table 5 provides a summary of system requirements:

Table 5. System Requirements

1 GHz or faster processor (2GHz, recommended)
1 GB of RAM (2 GB, recommended)
Microsoft® Windows XP
Microsoft® Excel 2003
Microsoft® .NET Framework 1.1
Microsoft® Visual J# .NET Redistributable Package 1.1

[21] If the software exhausts the available physical RAM, it will begin using the system's virtual memory (*i.e.*, the hard disk) and will slow dramatically. Insufficient memory may also cause the software to behave unexpectedly.

[22] The software is not compatible with other versions of the Framework (*e.g.*, 1.0 or 2.0 and above) and will not install or run unless the .NET Framework 1.1 is present on the system.

[23] The software requires the Visual J# .NET Redistributable Package 1.1. Versions 1.0, 2.0, or 2.0 second edition are not compatible.

Appendix B Operation

Appendix B.1 Install the software

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

The input files are:

- *demo_ parameters.xls*: inputs used to calculate the energy and emissions of changes in vehicle characteristics and sales volumes, as well as some assumptions used when simulating compliance
- *demo_emissions_rates.xls*: inputs used to project the emissions rates of various pollutants
- *demo_market_data.xls*: vehicle model, engine, and transmission characteristics and vehicle model sales volumes
- *demo_scenarios.xls*: inputs used to define different CAFE scenarios
- *demo_technologies.xls*: technology cost, efficiency, and availability assumptions

The demonstration file defining the initial state of the fleet—*demo_market_data.xls*—contains fictitious entries for many fields. Therefore, when used with this file, the system will produce fictitious results. Though useful for diagnostic purposes, such results should be treated as otherwise meaningless.

Step 2: To run the CAFE model, open the model using the **Start Menu→CAFE Model 2008→CAFE Model 2008** to open the main control window.[24]

- Read through the warnings and click the Yes button to continue (see Figure 10).

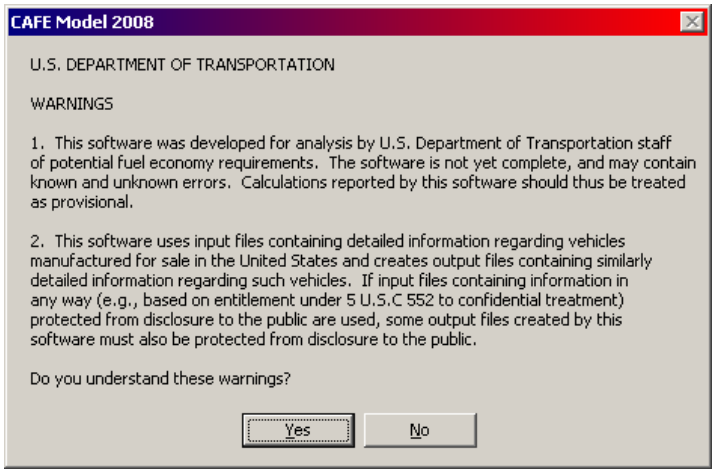

Figure 10. Warnings Dialog Box

- The main control window opens (Figure 11).

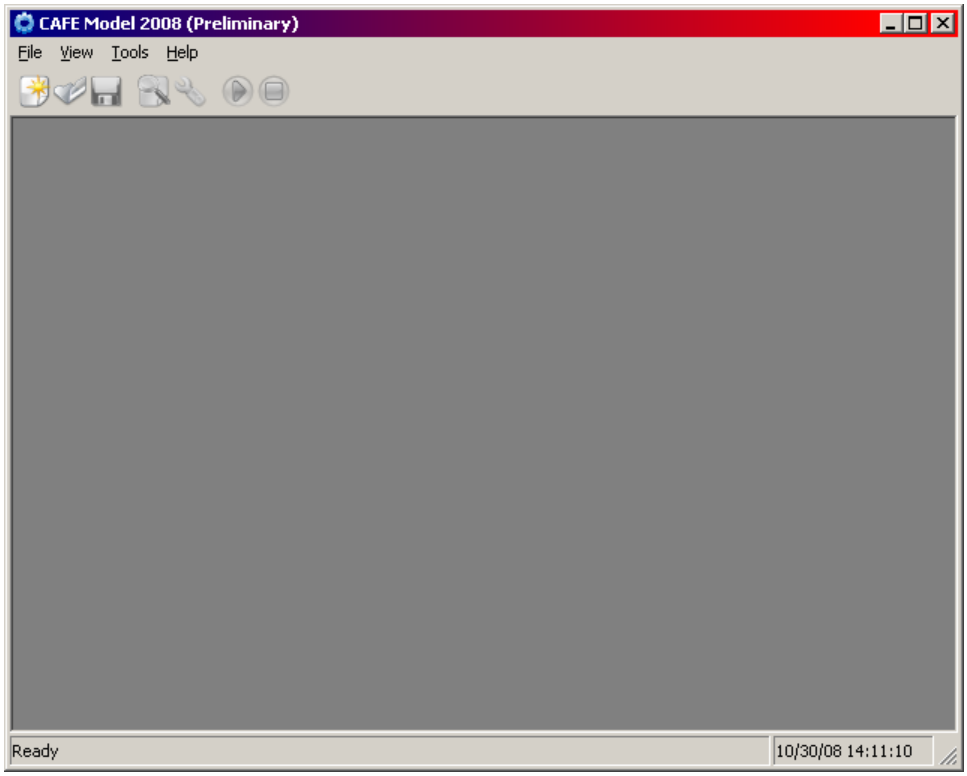

Figure 11. Initial Main Control Window

[24] Because the software slows dramatically if the physical RAM is fully utilized, we recommend closing other applications while you're running the software.

Step 3: Create a new CAFE session, using the New Session Wizard. If you have previously created a session, proceed to Step 4.

- Select **File > New Session**, press **Ctrl+N**, or click on the new session button ( ).

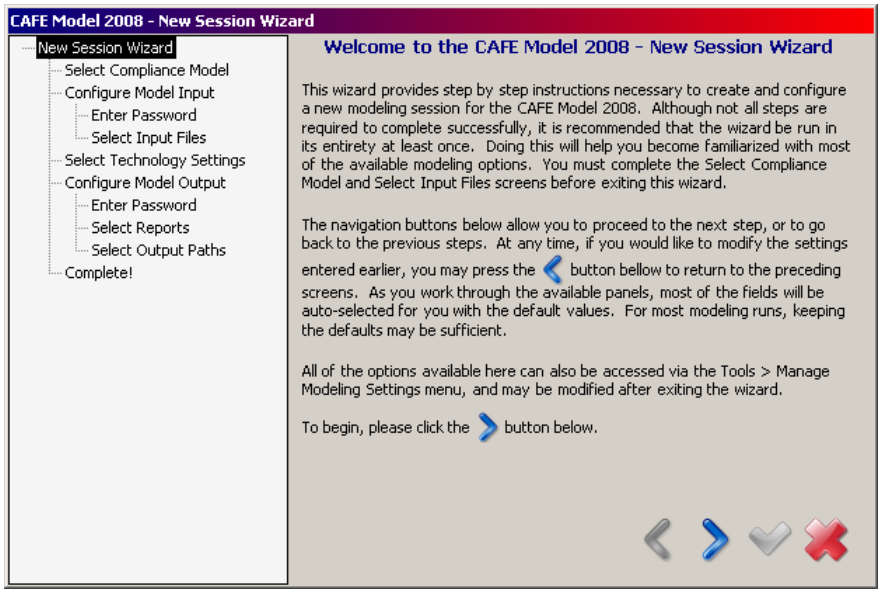

Figure 12. New Session Wizard Screen 1

- Follow the instructions provided by the wizard (Figure 12). Click the next button ( ) to continue.
- Select the desired Compliance Model (Figure 13) type and click the next button. Additional modeling types are available to assist in automated optimization and sensitivity analysis.

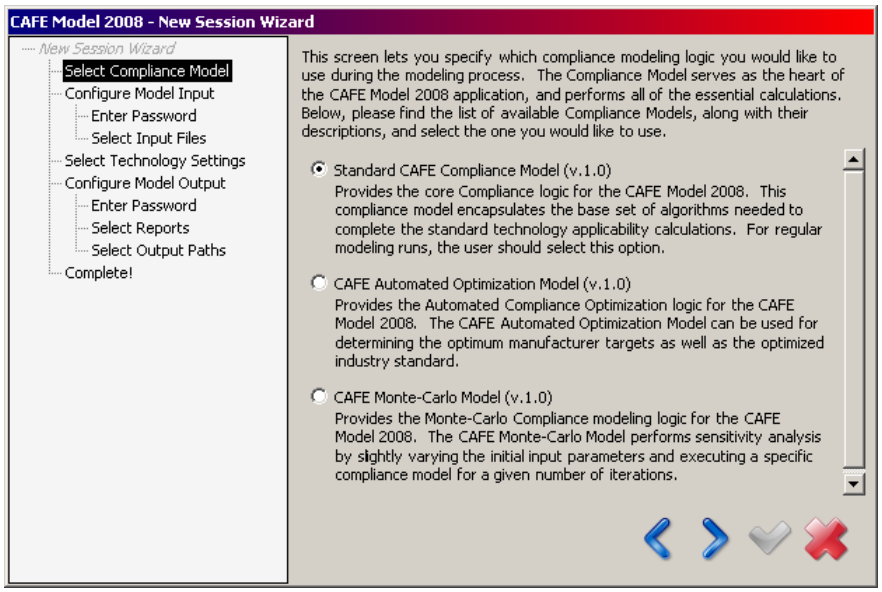

Figure 13. Compliance Model Selection

- Configure the Model Input by optionally specifying an input password and selecting the desired input files.
- If the input files are password protected, select the "Yes …" checkbox and click next (Figure 14). Otherwise, simply click the next button.

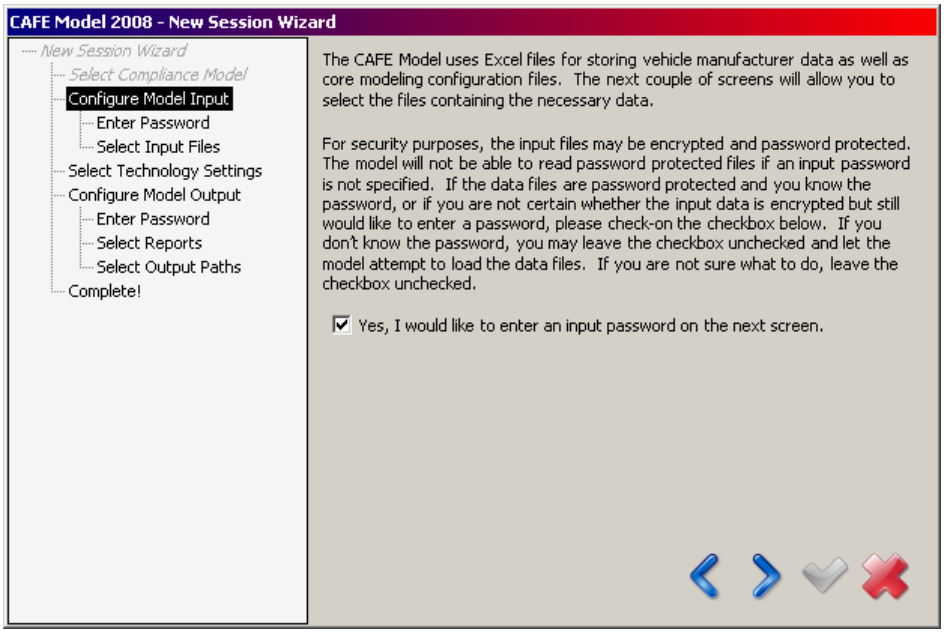

Figure 14. Configure Model Input Window

- If the input files are password protected, enter and verify the password to use for loading the Excel files (Figure 15). Note: passwords are case sensitive. Click the next button to continue.

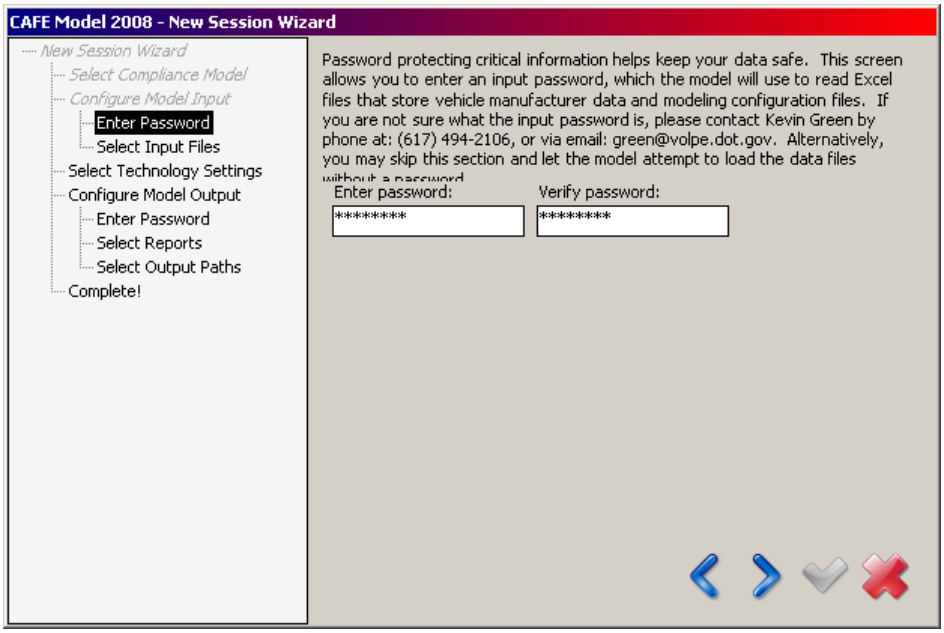

Figure 15. Enter Password for Input Files

- Select the desired Input Files by clicking on the browse buttons next to the textboxes or typing in the file path directly (Figure 16).

- You may also drag and drop single or multiple files into the wizard, or drag and drop a folder containing the input files. The model will check and auto-select the files required for input.

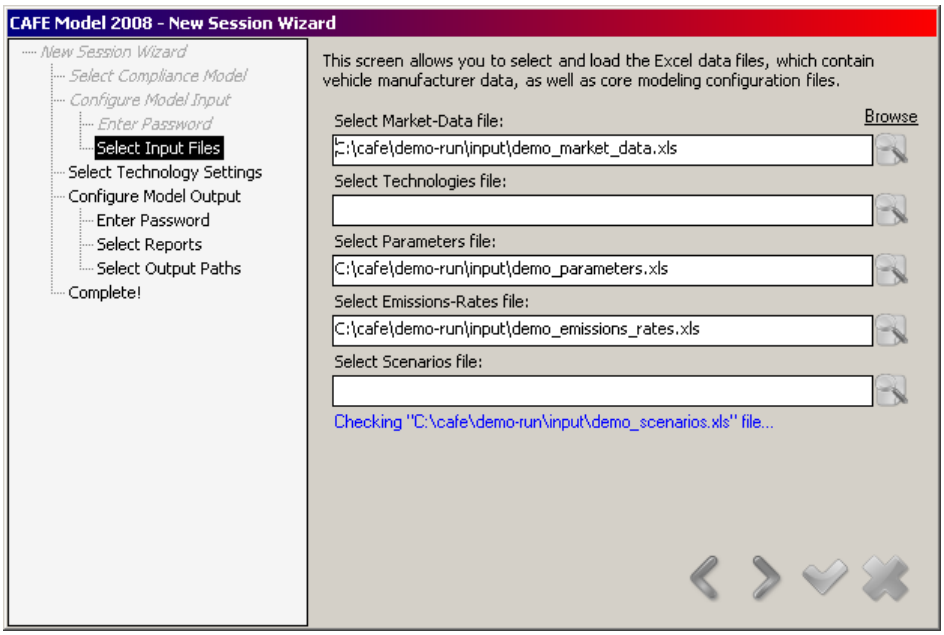

Figure 16. Select Input Files

- Select the desired Technology Settings and click the next button (Figure 17).

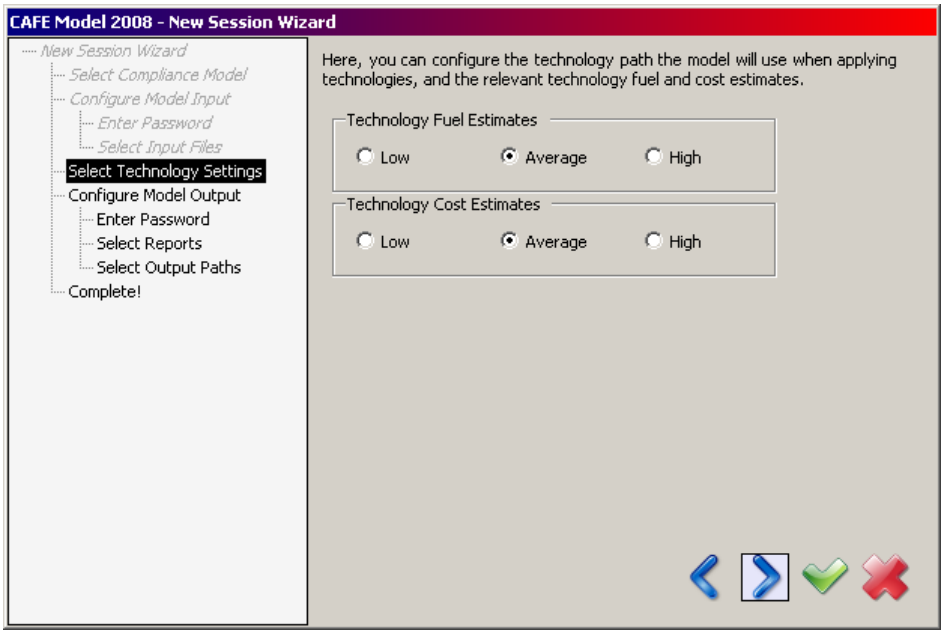

Figure 17. Select Technology Settings

- Configure the Model Output by optionally entering a password and selecting the desired reports and output location (Figure 18).
- If you decided to password-protect the output files, select the "Yes …" checkbox and click next. Otherwise, simply click the next button.

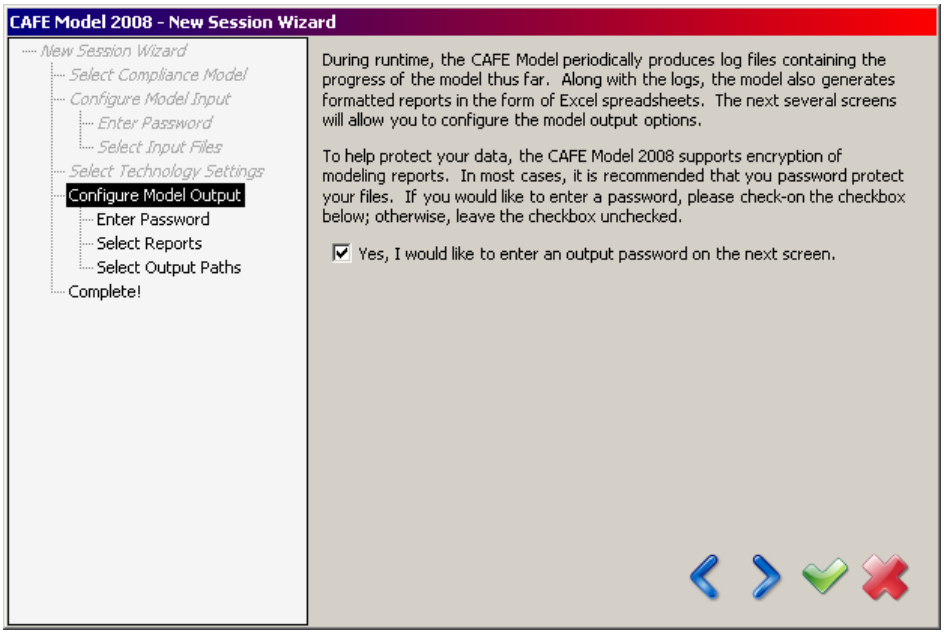

Figure 18. Configure Model Output

- Enter and verify the password to use for saving the Excel reports (Figure 19). Note: passwords are case sensitive. Click the next button to continue.

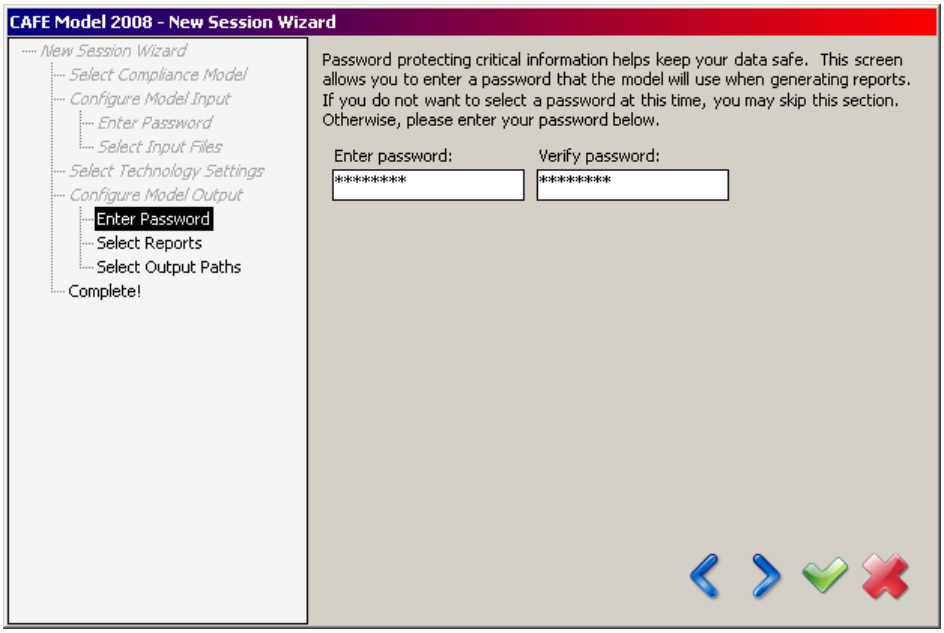

Figure 19. Enter Password for Output Files

- Select the desired Reports and click next (Figure 20).

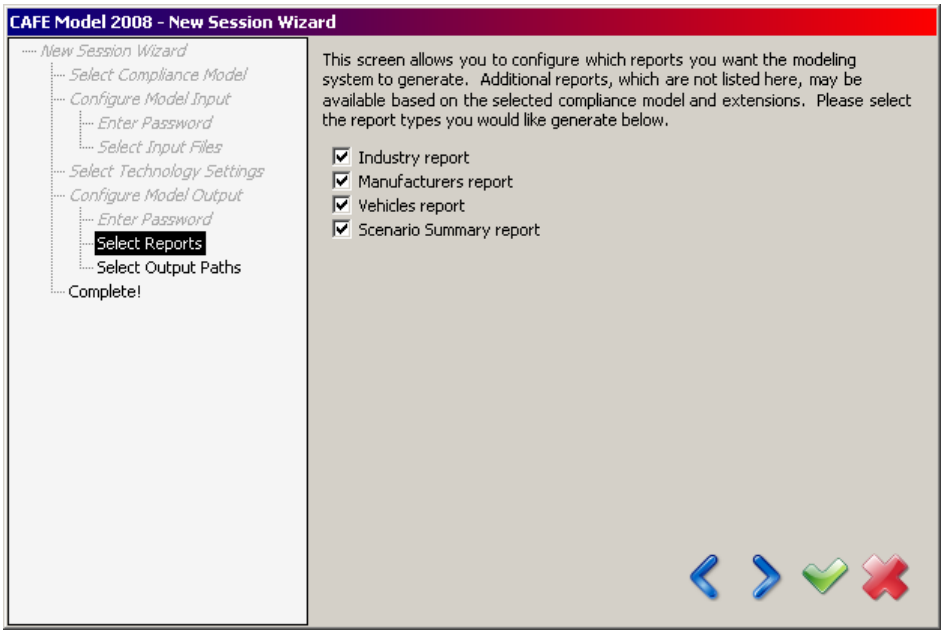

Figure 20. Select Reports

- Select the Output Path where the model will write log files and reports by clicking the browse button next to the textbox or by entering the folder location directly (Figure 21). Click the next button to continue.

Figure 21. Select Output Path

- Complete the New Session Wizard by entering a session name and clicking the apply button ( )(Figure 22).
- You may also save the newly created session after exiting the wizard.[25]

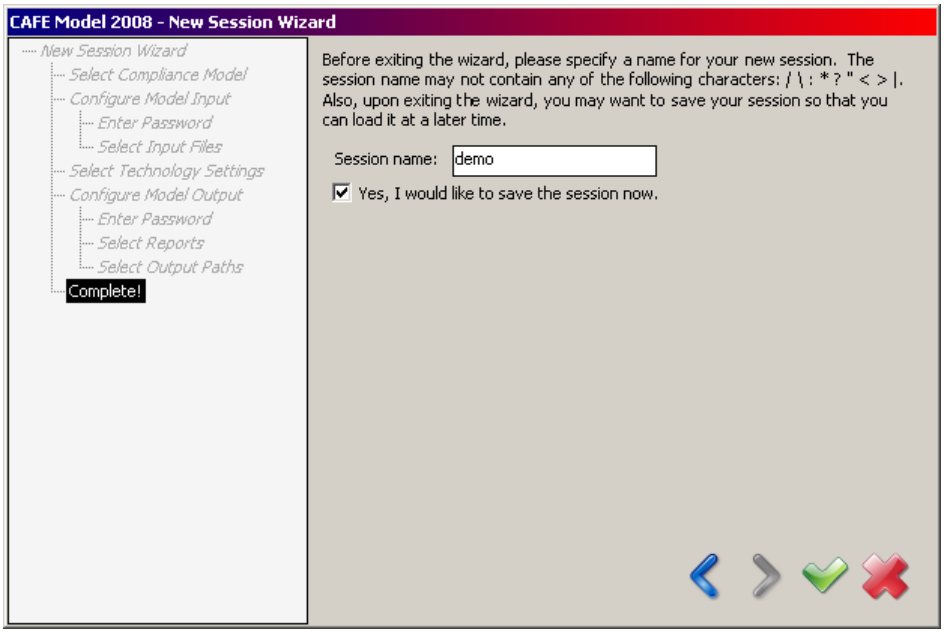

Figure 22. Completing the New Session Wizard

- Wait for the wizard to complete loading files and settings.

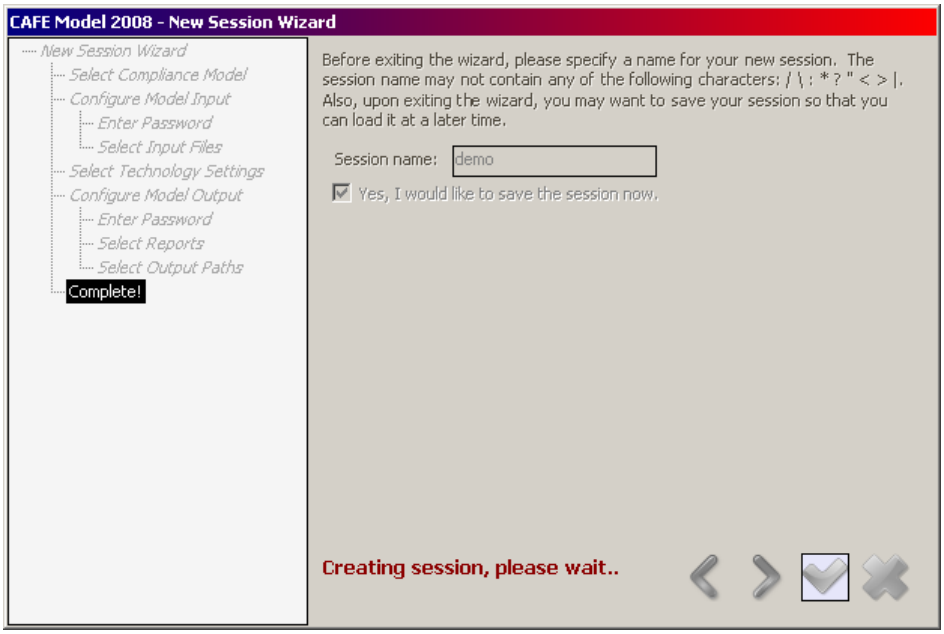

Figure 23. Creating New Session

[25] Saving sessions allows bypassing of the wizard during future runs, as long as the input files and settings remain the same.

- All of the settings configured above, as well as the advanced options not available in the wizard, are accessible by selecting **Tools > Modeling Settings**, pressing **Ctrl+T**, or clicking on the configure modeling settings button ( ).
- The wizard for any existing session may be re-run by selecting **Tools > Run New Session Wizard** or by pressing **Ctrl+W**.
- If you decided to save the session after exiting the wizard, select the location for the session file and click the **Save** button.

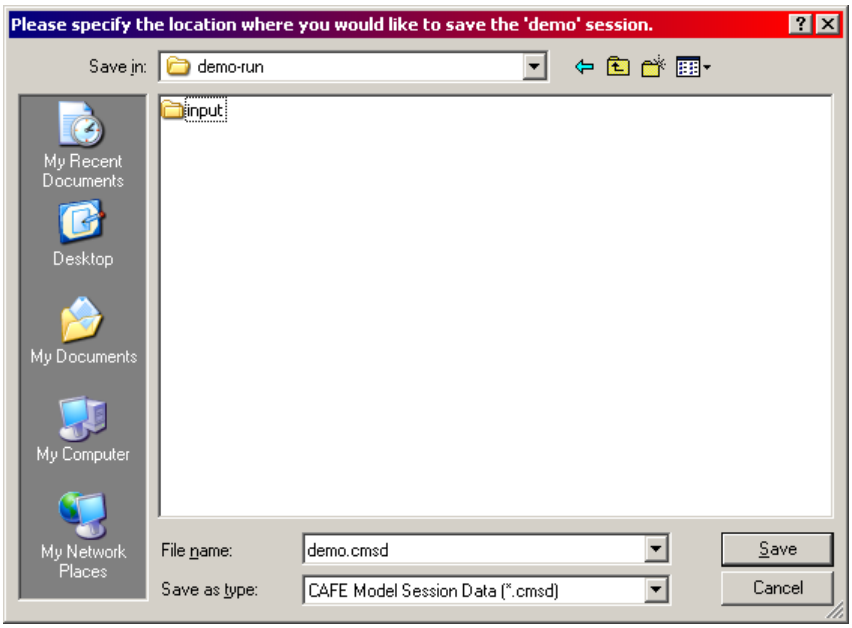

Figure 24. Saving the Session

- Proceed to **Step 5 (Appendix C on page 47)**.

Appendix B.4 Open an existing CAFE Session.

Step 4: Open an existing CAFE Session. If you have created a new session in Step 3, proceed to Step 5 **(Appendix C below)**.

- Select **File** > **Open Session**, press **Ctrl+O**, or click on the open session button ( ).
- Locate the previously saved session (file with an **.cmsd** extension) and click the **Open** button (Figure 25).

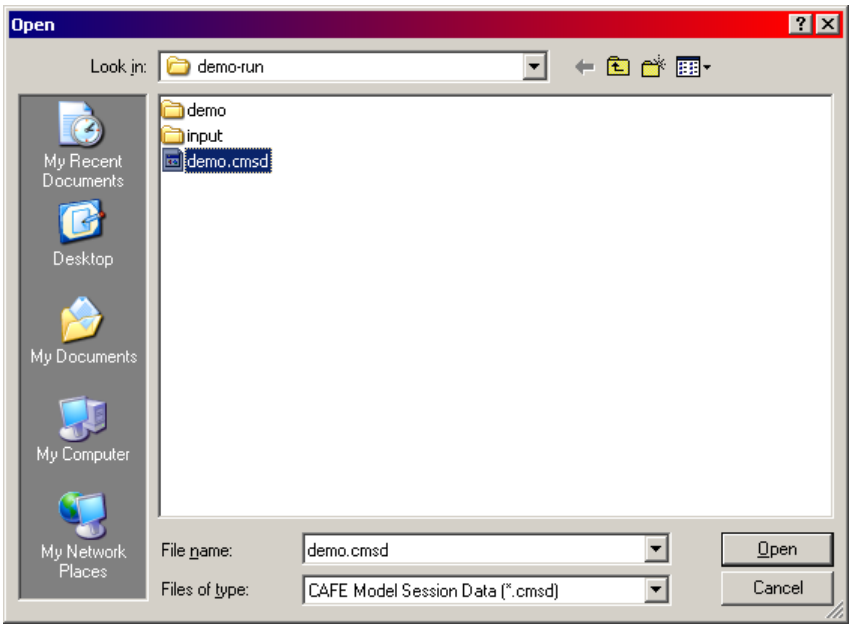

Figure 25. Open an Existing Session File

- To configure the modeling settings for the opened session, select **Tools** > **Modeling Settings**, press **Ctrl+T**, or click on the configure modeling settings button ( ).
- You may re-run the **New Session Wizard** for any opened session by selecting **Tools** > **Run New Session Wizard** or by pressing **Ctrl+W**.
- Proceed to **Step 5 (Appendix C below)**.

Appendix C Start the Modeling Process.

Step 5: Return to the main control window and start the modeling process.

- Select **File** > **Start Modeling**, press **Ctrl+M**, or click the start modeling button ( ), which has now become enabled (Figure 26).

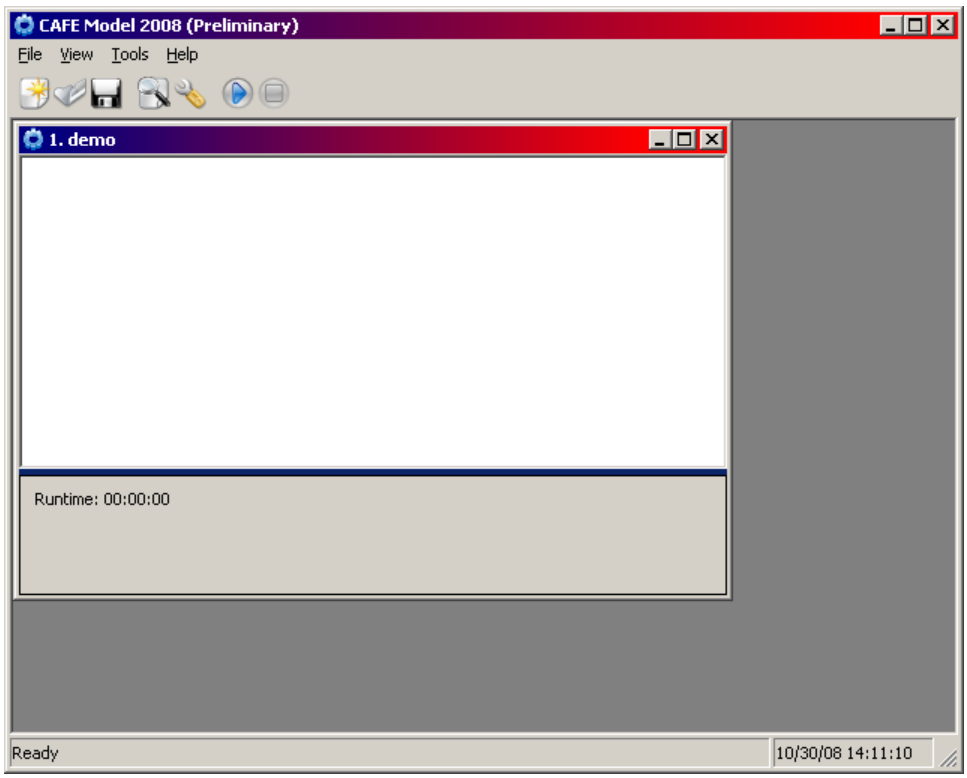

Figure 26. Running the Model

- While the compliance modeling process is running, the model displays various progress information in the session body.

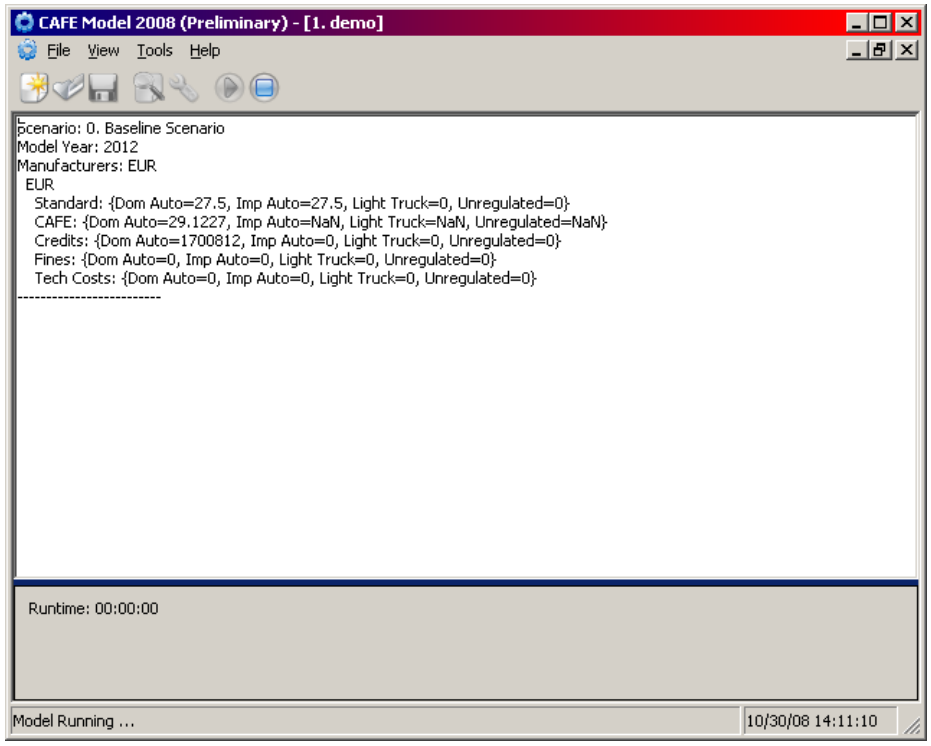

Figure 27. Model Run Example One

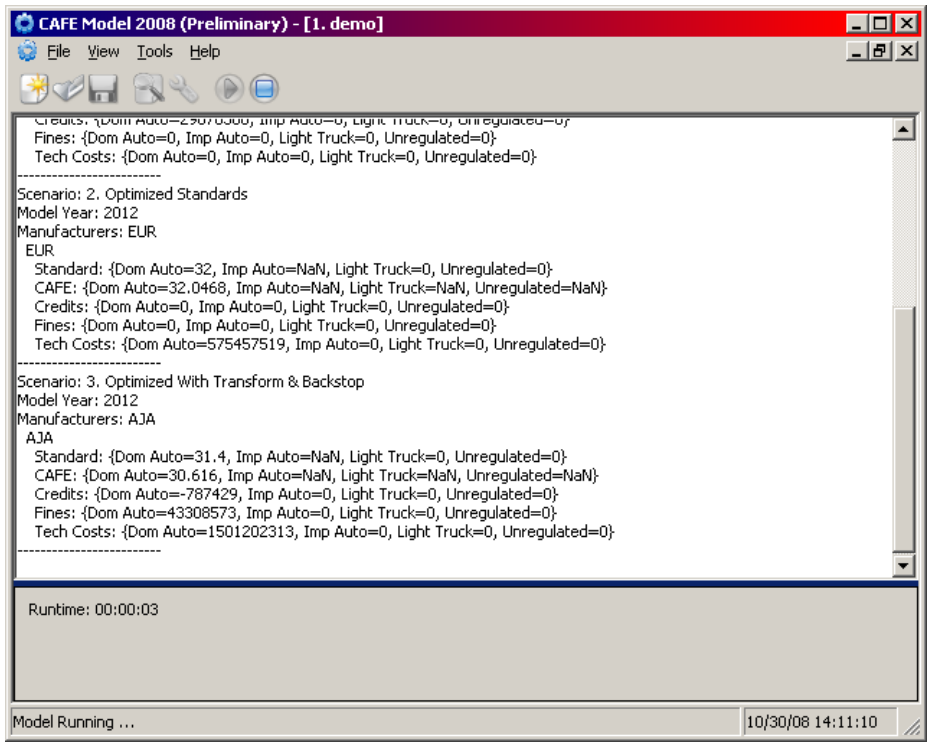

Figure 28. Model Run Example Two

- The modeling process has concluded when “Modeling Completed!” appears at the bottom of the main control window (Figure 29).

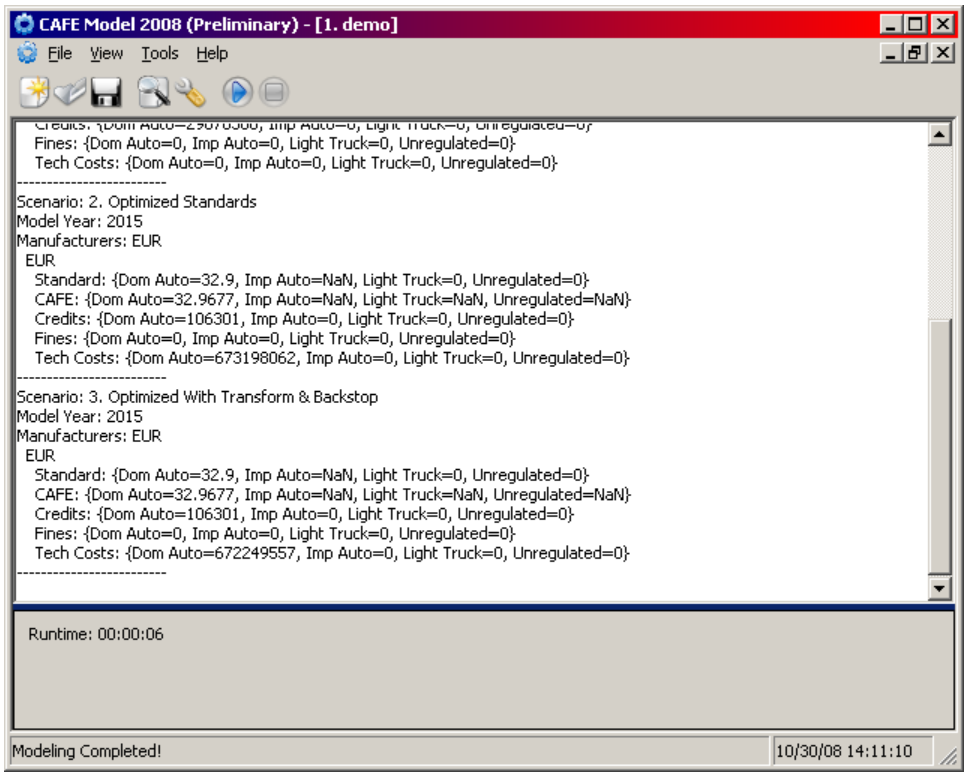

Figure 29. Modeling Complete

Step 6: Generate the modeling reports.

- To review the modeling reports selected for output, select **Tools** > **Manage Output** or press **Ctrl+U**.

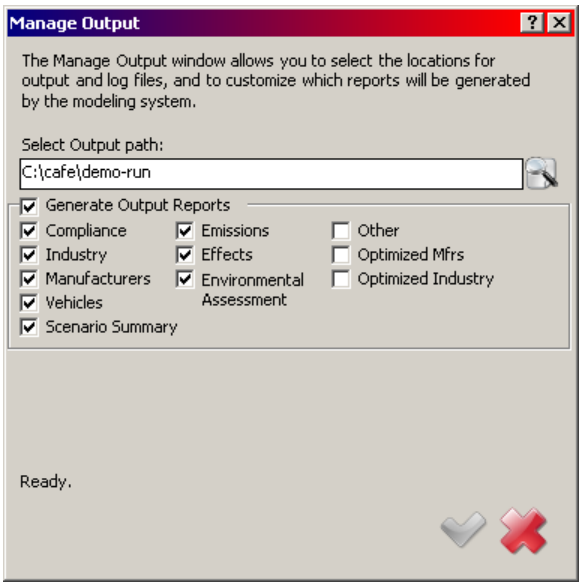

Figure 30. Manage Output for Modeling Reports

- Select the desired reports, click save ( ), then close ( ) (Figure 30).

- Generate the modeling reports by selecting **File > Generate Reports** or pressing **Ctrl+R (**Figure 31**)**.

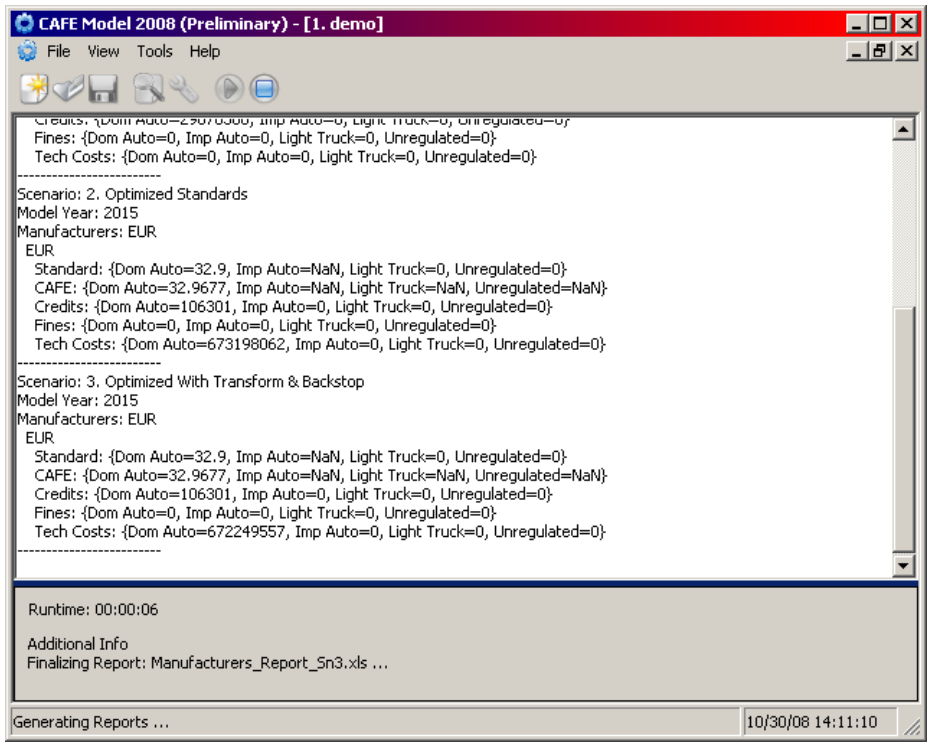

Figure 31. Generate Reports

- Wait for "Reporting Completed!" to appear at the bottom of the main control window (Figure 32).

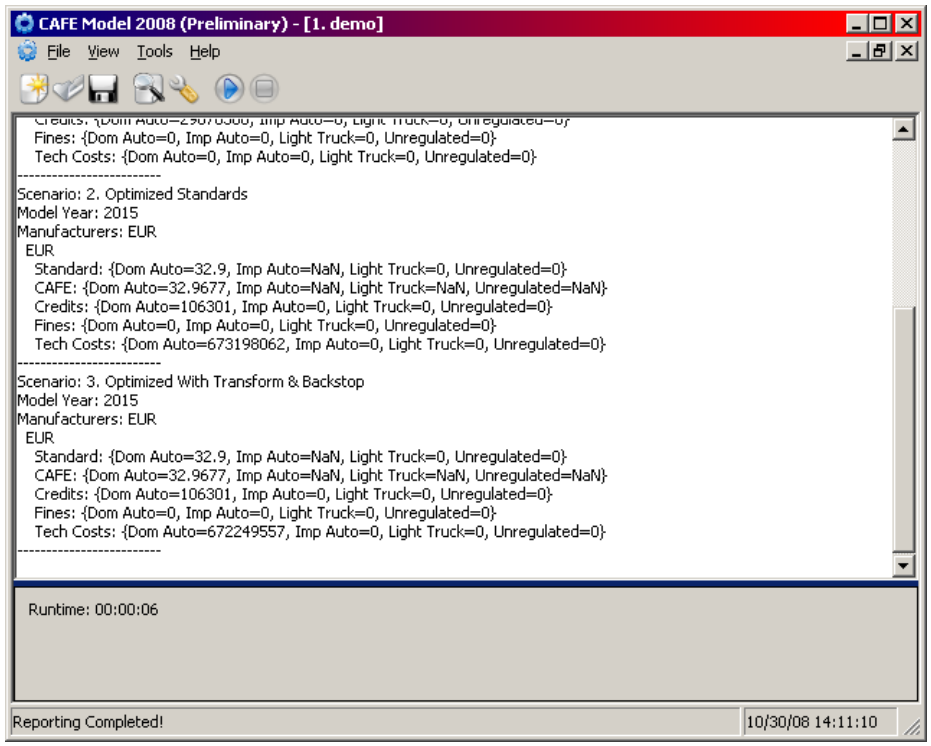

Figure 32. Reporting Complete

Step 7: Exit the CAFE modeling application.

- Select **File** > **Exit**, press **Alt+F4**, or click the close button (**X**) at the top-right corner of the main control window.
- A "Save Session?" dialog will appear (Figure 33). You may press **Yes**, to save the session, or **No** (recommended), to discard saving the session.

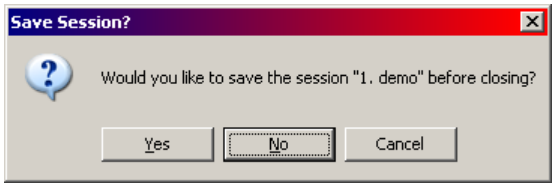

Figure 33. Save Session Before Closing

Step 8: View results by opening appropriate output files.

The model saves all log files and reports to the output folder specified in **Step 3**, organized by the session name. Thus, in the example session created in **Step 3**, the outputs will be located under **C:\cafe\demo-run\demo**, where **C:\cafe\demo-run** is the selected output path and "**demo**" is the name of the session.

The modeling reports for all included scenarios are saved in the ***reports*** folder (Figure 34). The per-scenario reports are numbered in order of appearance, starting at 0. The first scenario (0) is identified as the baseline scenario to which all others are compared. The following files are produced if specified in **Steps 3 (Appendix B.3) or 6 (Appendix C.1)**.

- *Industry_Report_Sn*.xls*: Industry- and manufacturer-level summary of compliance model results, showing all model years per worksheet for individual manufacturers and overall industry results.
- *Manufacturer_Report_Sn*.xls*: Industry- and manufacturer-level summary of compliance model results, showing all manufacturers and overall industry results, with one model year per worksheet.
- *Vehicles_Report_Sn*.xls*: Vehicle-level summary of compliance model results.
- *Effects_Report_Sn*.xls*: Summary of energy and emissions effects.
- *EA_Report.xls*: Summary of fuel consumption and emissions effects.
- *ScenSummary_Report.xls*: Summary of industry- and manufacturer-level compliance and effects results, compared versus the baseline across all scenarios.

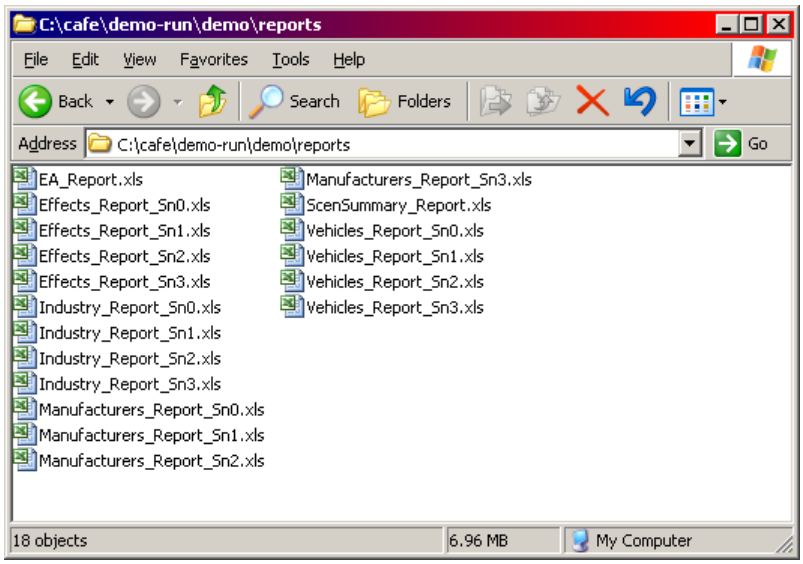

Figure 34. Reports Folder

The file defining the initial state of the fleet—*demo_market_data.xls*—contains fictitious entries for many fields. Therefore, when used with this file, the system will produce

fictitious results. Though useful for diagnostic purposes, such results should be treated as otherwise meaningless.

To review input files, modeling settings, and scenario descriptions used during modeling, open *Summary.txt*, which is located in the ***logs*** folder (Figure 35).

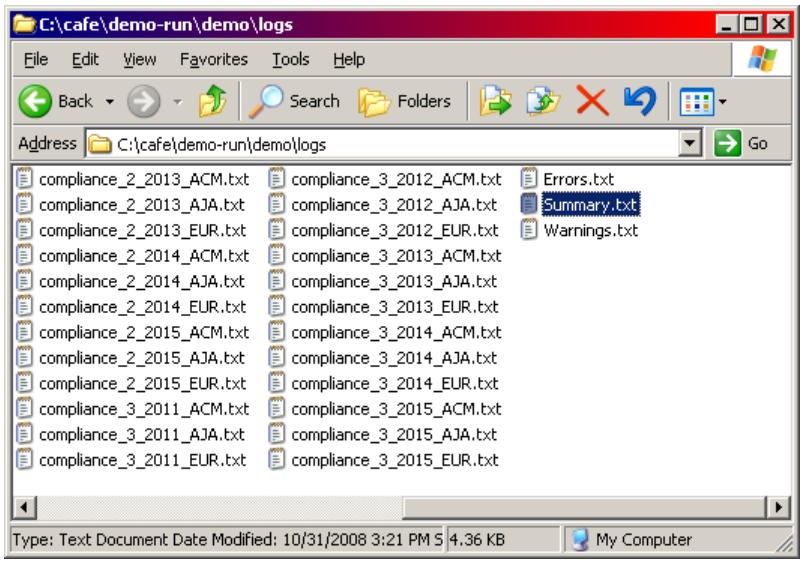

Figure 35. Modeling Logs Folder

The ***logs*** folder also contains the *Errors.txt* file, which identifies errors that occurred during modeling, the *Warnings.txt* file, which specifies any modeling warnings, and *compliance_*.txt* files, which hold compliance findings applied to each of the manufacturers during a specific scenario and model year.

Appendix D Inputs

Appendix D.1 Overview

In addition to various operational settings that are, as discussed in Appendix B, specified by the user at the time the system is initiated, the system utilizes the five input files (all in Microsoft® Excel format) shown in Table 6. As discussed in Appendix B, the user specifies the location of these files in the course of setting up a model run. 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 6. Input File Contents

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

Emissions Rates	inputs used to project the emissions rates of various pollutants

Appendix D.2 Market Data File

The market data file has four worksheets, Manufacturers, Vehicle Models, Engines and Transmissions.

Appendix D.2.1 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.

Table 7. Manufacturers Worksheet

Category	Manufacturer Characteristic	Units	Definition/Notes
General	Manufacturer Code	integer	unique number assigned to each manufacturer
	Manufacturer Name	text	name of manufacturer
	Cost Allocation Strategy	integer	strategy for distributing aggregate technology costs and, if applicable, fines
	Avg. CW of MY02 Lt. Trucks	pounds	
	Discount Rate	percent	manufacturer specific discount rate to apply to effectiveness calculations
	Optimize	text	Y = consider this manufacturer for optimization; N = do not consider for optimization
Willingness To Pay CAFE Fines	2011	text	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	

Appendix D.2.2 Vehicle Models Worksheet

The vehicle models worksheet contains information regarding each vehicle model offered for sale during the study period. Each vehicle model is represented as a single row of input data. Table 8 through Table 11 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 number, 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 engine and transmission input files.

Table 8. Vehicle Models Worksheet

Category	Vehicle Characteristic	Units	Definition/Notes
General	Number	integer	unique number assigned to each model
	Manufacturer	text	manufacturer abbreviation
	Model	text	name of model (i.e., Camry)
	Nameplate	text	vehicle nameplate (i.e., Camry Solara)
	Fuel Economy	mpg	weighted (FTP+highway) fuel economy
	Actual FE (FFVs)	mpg	for flexible fuel vehicles, fuel economy when vehicle is operated on gasoline only
	Engine Code	integer	unique number assigned to each engine
	Transmission Code	integer	unique number assigned to each transmission
	Origin	text	classification as domestic or import
	Technology Class	text	the technology class to which this vehicle belongs
	General Notes	text	explanatory notes

Within the "Vehicle" category, it is important that each vehicle model's style, class, drive, curb weight or test weight, wheelbase, front and rear track width, and fuel capacity be specified. For any hybrid vehicle models, it is necessary to specify at least the type of hybridization.

Table 9. Vehicle Models Worksheet (continued)

Category	Vehicle Characteristic	Units	Definition/Notes
Vehicle	Style	text	vehicle style
	Class	text	vehicle class
	Structure	text	vehicle structure (e.g., ladder, unibody)
	Drive	text	vehicle drive (e.g., A=all-wheel drive; F=front-wheel drive; R=rear-wheel-drive; 4=4-wheel drive)
	Wheelbase	inches	per SAE J1100, L101 (Sept. 2005)
	Track Width (front)	inches	per SAE J1100, W101-1 (Sept. 2005), measured when tires are mounted on rims with zero offset
	Track Width (rear)	inches	per SAE J1100, W101-2 (Sept. 2005), measured when tires are mounted on rims with zero offset
	Footprint	sq. feet	wheelbase times average track width
	Curb Weight	pounds	total weight of vehicle including batteries, lubricants, and other expendable supplies but excluding the driver, passengers, and other payloads (SAE J1100)
	Test Weight	pounds	weight of vehicle as tested, including the driver, operator (if necessary), and all instrumentation (SAE J1263)
	GVWR	pounds	Gross Vehicle Weight Rating; weight of loaded vehicle, including passengers and cargo
	Fuel Capacity	gallons	gallons of diesel fuel or gasoline; MJ (LHV) of other fuels (or chemical battery energy)
	Seating (max)	integer	number of usable seat belts before folding and removal of seats (where accomplished without special tools)
	Type (Hybridization)	text	type of hybridization, if any
	Vehicle Notes	text	explanatory notes

In the "Planning & Assembly" section, it is important that the number of any (single) predecessor to the current vehicle model be specified. The redesign and refresh years must be comma separated and contain all known previous and projected future redesign and refresh years. 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.

Table 10. Vehicle Models Worksheet (continued)

Category	Vehicle Characteristic	Units	Definition/Notes
Planning & Assembly	US Content	percent	overall percentage, by value, that originated in U.S.
	Canadian Content	percent	overall percentage, by value, that originated in Canada
	Mexican Content	percent	overall percentage, by value, that originated in Mexico
	Predecessor	integer	number of model upon which current model is based
	Redesign Years	model year	comma separated list of previous and future redesign years of the vehicle
	Refresh Years	model year	comma separated list of previous and future refresh years of the vehicle
	Employment Hours Per Vehicle	hours	number of hours of U.S. labor applied per vehicle produced
	% 2 DR Cars	percent	share of vehicle models with 2 or 3 doors
	Market Segment - Auto News	integer	coded market share per *2002 Automotive News Market Classifications*
	Planning & Assembly Notes	text	explanatory notes
Sales	MY2011	units	projected production for sale in U.S.
	MY2012	units	projected production for sale in U.S.
	MY2013	units	projected production for sale in U.S.
	MY2014	units	projected production for sale in U.S.
	MY2015	units	projected production for sale in U.S.
	Sales Notes	text	explanatory notes
MSRP	MY2011	dollars	projected average MSRP (sales-weighted, including options)
	MY2012	dollars	projected average MSRP (sales-weighted, including options)
	MY2013	dollars	projected average MSRP (sales-weighted, including options)
	MY2014	dollars	projected average MSRP (sales-weighted, including options)
	MY2015	dollars	projected average MSRP (sales-weighted, including options)
	MSRP Notes	text	explanatory notes

The applicability of technologies considered on a vehicle model basis (as opposed, for example, to an engine basis) can be controlled for each vehicle model by using the "Technology Applicability Overrides". As discussed in section 2.2.2, the applicability of a given technology to a given vehicle is first tested by considering the choice of "technology path" specified in the technology input file (discussed below). However, if any overrides are specified in the vehicle models file, they will preempt the technology path.

Table 11. Vehicle Models Worksheet (continued)

Category	Vehicle Characteristic	Units	Definition/Notes
Technology Applicability Overrides	EPS	text	force system to set as "USED" or "SKIP" Electric Power Steering
	IACC	text	force system to set as "USED" or "SKIP" Improved Accessories
	MHEV	text	force system to set as "USED" or "SKIP" 12V Micro-Hybrid
	HVIA	text	force system to set as "USED" or "SKIP" Higher Voltage/Improved Alternator
	BISG	text	force system to set as "USED" or "SKIP" Belt mounted Integrated Starter Generator
	CISG	text	force system to set as "USED" or "SKIP" Crank mounted Integrated Starter Generator
	PSHEV	text	force system to set as "USED" or "SKIP" Power Split Hybrid
	2MHEV	text	force system to set as "USED" or "SKIP" 2-Mode Hybrid
	PHEV	text	force system to set as "USED" or "SKIP" Plug-in Hybrid
	MS1	text	force system to set as "USED" or "SKIP" Material Substitution (1%)
	MS2	text	force system to set as "USED" or "SKIP" Material Substitution (2%)
	MS5	text	force system to set as "USED" or "SKIP" Material Substitution (5%)
	ROLL	text	force system to set as "USED" or "SKIP" Low Rolling Resistance Tires
	LDB	text	force system to set as "USED" or "SKIP" Low Drag Brakes
	SAXU	text	force system to set as "USED" or "SKIP" Secondary Axle Disconnect - Unibody
	SAXL	text	force system to set as "USED" or "SKIP" Secondary Axle Disconnect - Ladder Frame
	AERO	text	force system to set as "USED" or "SKIP" Aero Drag Reduction

Appendix D.2.3 Engines Worksheet

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

Table 12. Engines Input Worksheet

Engine Characteristic	Units	Definition/Notes
Engine Code	integer	unique number assigned to each engine
Manufacturer	text	manufacturer abbreviation
Name	text	name of engine
Configuration	text	configuration of the engine
Fuel	text	most common fuel with which engine is compatible
Country of Origin	text	name of country where engine is manufactured
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
Air/Fuel Ratio	number	weighted (FTP+highway) air/fuel ratio (mass)
Fuel System	text	mechanism that delivers fuel to engine
Aspiration	text	breathing or induction process of 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
Compression Ratio (Min)	number	for fixed CR engines, should be identical to maximum CR
Compression Ratio (max)	number	for fixed CR engines, should be identical to minimum CR
Horsepower	number	maximum power (horsepower)
Torque	number	maximum torque (pound-foot)
Engine Notes	text	explanatory notes
LUB	text	force system to set as "USED" or "SKIP" Low Friction Lubricants
EFR	text	force system to set as "USED" or "SKIP" Engine Friction Reduction
CCPS	text	force system to set as "USED" or "SKIP" VVT - Coupled Cam Phasing (CCP) on SOHC
DVVLS	text	force system to set as "USED" or "SKIP" Discrete Variable Valve Lift (DVVL) on SOHC
DEACS	text	force system to set as "USED" or "SKIP" Cylinder Deactivation on SOHC
ICP	text	force system to set as "USED" or "SKIP" VVT - Intake Cam Phasing (ICP)
DCP	text	force system to set as "USED" or "SKIP" VVT - Dual Cam Phasing (DCP)
DVVLD	text	force system to set as "USED" or "SKIP" Discrete Variable Valve Lift (DVVL) on DOHC
CVVL	text	force system to set as "USED" or "SKIP" Continuously Variable Valve Lift (CVVL)
DEACD	text	force system to set as "USED" or "SKIP" Cylinder Deactivation on DOHC
DEACO	text	force system to set as "USED" or "SKIP" Cylinder Deactivation on OHV
CCPO	text	force system to set as "USED" or "SKIP" VVT - Coupled Cam Phasing (CCP) on OHV
DVVLO	text	force system to set as "USED" or "SKIP" Discrete Variable Valve Lift (DVVL) on OHV
CDOHC	text	force system to set as "USED" or "SKIP" Conversion to DOHC with DCP
SGDI	text	force system to set as "USED" or "SKIP" Stoichiometric Gasoline Direct Injection (GDI)
CBRST	text	force system to set as "USED" or "SKIP" Combustion Restart
TRBDS	text	force system to set as "USED" or "SKIP" Turbocharging and Downsizing
EGRB	text	force system to set as "USED" or "SKIP" Exhaust Gas Recirculation (EGR) Boost
DSLT	text	force system to set as "USED" or "SKIP" Conversion to Diesel following TRBDS
DSLC	text	force system to set as "USED" or "SKIP" Conversion to Diesel following CBRST

Appendix D.3 Transmissions Worksheet

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

Table 13. Transmission Input Worksheet

Transmission Characteristic	Units	Definition/Notes
Transmission Code	integer	unique number assigned to each transmission
Manufacturer	text	manufacturer abbreviation
Name	text	name of transmission
Country of Origin	text	name of country where transmission is manufactured
Type	text	type of transmission
Number of Forward Gears	integer	
Control	text	ASMT would be coded as Type=C, Control=A
Logic	text	aggressivity of automatic shifting
Transmission Notes	text	explanatory notes
6MAN	text	force system to set as "USED" or "SKIP" 6 Speed Manual Transmission
IATC	text	force system to set as "USED" or "SKIP" Improved Automatic Transmission Controls/Externals
CVT	text	force system to set as "USED" or "SKIP" Continuously Variable Transmission
NAUTO	text	force system to set as "USED" or "SKIP" 6/7/8-Speed Automatic Transmission with Improved Internals
DCTAM	text	force system to set as "USED" or "SKIP" Dual Clutch or Automated Manual Transmission

Taken together, the manufacturers, vehicle models, engines, and transmissions input files provide “initial state” historical and/or forecast data for the light vehicle fleet.

Appendix D.4 Technologies

The technologies input file contains assumptions regarding the fuel consumption benefit, cost, applicability, and availability of different vehicle, engine, and transmission technologies during the study period. Input assumptions are specific to each of the following vehicle types: small SUVs, midsize SUVs, large SUVs, minivans, small pickups, large pickups, subcompact cars, compact cars, midsize cars, and large cars. Table 14 shows sample technology assumptions for small SUVs:

Table 14. Technologies Input File (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 Threshold	Learning Rate	Aux.	Applicability	Phase-in 2011	Phase-in 2012	Phase-in 2013	Phase-in 2014	Phase-in 2015
1	Low Friction Lubricants	LUB	EngMod	2007	0.50%	0.50%	$ 5	$ 5					TRUE	50%	100%	100%	100%	100%
2	Engine Friction Reduction	EFR	EngMod	2007	1.00%	2.00%	$ 13	$ 49					TRUE	20%	40%	60%	80%	100%
3	VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	EngMod	2007	1.00%	2.90%	$ 61	$ 61	TIME		0.03		TRUE	15%	35%	55%	75%	100%
4	Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	EngMod	2007	1.00%	2.90%	$ 201	$ 201	TIME		0.03		TRUE	15%	35%	55%	75%	100%
5	Cylinder Deactivation on SOHC	DEACS	EngMod	2007	0.00%	0.00%	$ -	$ -					FALSE	9%	17%	34%	51%	68%
6	VVT - Intake Cam Phasing (ICP)	ICP	EngMod	2007	1.00%	2.00%	$ 61	$ 61	TIME		0.03		TRUE	15%	35%	55%	75%	100%
7	VVT - Dual Cam Phasing (DCP)	DCP	EngMod	2007	2.00%	3.00%	$ 61	$ 61	TIME		0.03		TRUE	15%	35%	55%	75%	100%
8	Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	EngMod	2007	1.00%	2.90%	$ 201	$ 201	TIME		0.03		TRUE	15%	35%	55%	75%	100%
9	Continuously Variable Valve Lift (CVVL)	CVVL	EngMod	2007	1.50%	3.50%	$ 306	$ 306	TIME		0.03		TRUE	15%	35%	55%	75%	100%
10	Cylinder Deactivation on DOHC	DEACD	EngMod	2007	0.00%	0.00%	$ -	$ -					FALSE	9%	17%	34%	51%	68%
11	Cylinder Deactivation on OHV	DEACO	EngMod	2007	0.00%	0.00%	$ -	$ -					FALSE	9%	17%	34%	51%	68%
12	VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	EngMod	2007	1.00%	1.50%	$ 61	$ 61	TIME		0.03		TRUE	15%	35%	55%	75%	100%
13	Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	EngMod	2007	0.50%	2.60%	$ 201	$ 201	TIME		0.03		TRUE	15%	35%	55%	75%	100%
14	Conversion to DOHC with DCP	CDOHC	EngMod	2007	1.00%	2.60%	$ 373	$ 373	TIME		0.03		TRUE	9%	17%	34%	51%	68%
15	Stoichiometric Gasoline Direct Injection (GDI)	SGDI	EngMod	2007	1.90%	2.90%	$ 73	$ 110	TIME		0.03		TRUE	3%	6%	20%	40%	60%
16	Combustion Restart	CBRST	EngMod	2007	1.80%	2.40%	$ 141	$ 141	TIME		0.03		TRUE	0%	0%	0%	3%	6%
17	Turbocharging and Downsizing	TRBDS	EngMod	2007	4.50%	5.20%	$ 1,223	$ 1,223	TIME		0.03		TRUE	9%	17%	34%	51%	68%
18	Exhaust Gas Recirculation (EGR) Boost	EGRB	EngMod	2007	3.90%	4.00%	$ 173	$ 173	TIME		0.03		TRUE	0%	0%	3%	6%	9%
19	Conversion to Diesel following TRBDS	DSLT	EngMod	2007	7.70%	6.60%	$ 1,858	$ 1,567	TIME		0.03		TRUE	3%	6%	9%	12%	15%
20	Conversion to Diesel following CBRST	DSLC	EngMod	2007	15.30%	15.00%	$ 3,254	$ 2,963	TIME		0.03		TRUE	3%	6%	9%	12%	15%
21	6-Speed Manual/Improved Internals	6MAN	TrMod	2007	0.50%	0.50%	$ 338	$ 338	TIME		0.03		TRUE	33%	67%	100%	100%	100%
22	Improved Auto. Trans. Controls/Externals	IATC	TrMod	2007	1.50%	2.50%	$ 59	$ 59	TIME		0.03		TRUE	33%	67%	100%	100%	100%
23	Continuously Variable Transmission	CVT	TrMod	2007	0.70%	2.00%	$ 300	$ 300	TIME		0.03		TRUE	5%	15%	30%	50%	80%
24	6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	TrMod	2007	1.40%	3.40%	$ 323	$ 323	TIME		0.03		TRUE	50%	75%	100%	100%	100%
25	Dual Clutch or Automated Manual Transmission	DCTAM	TrMod	2007	5.50%	7.50%	$ 68	$ 68	TIME		0.03		TRUE	20%	50%	100%	100%	100%
26	Electric Power Steering	EPS	ELEC	2007	1.00%	2.00%	$ 105	$ 120	TIME		0.03		TRUE	10%	35%	60%	85%	100%
27	Improved Accessories	IACC	ELEC	2007	1.00%	2.00%	$ 173	$ 211	TIME		0.03		TRUE	10%	30%	50%	75%	100%
28	12V Micro-Hybrid	MHEV	ELEC	2007	1.00%	2.90%	$ 372	$ 372	TIME		0.03		TRUE	3%	6%	9%	12%	15%
29	Higher Voltage/Improved Alternator	HVIA	ELEC	2007	0.20%	0.90%	$ 84	$ 84	TIME		0.03		TRUE	10%	30%	50%	75%	100%
30	Belt mounted Integrated Starter Generator	BISG	ELEC	2007	5.70%	6.50%	$ 1,713	$ 1,713	VOLUME	150,000	0.2		TRUE	3%	6%	9%	12%	15%
31	Crank mounted Integrated Starter Generator	CISG	ELEC	2007	0.00%	0.00%	$ -	$ -					FALSE	0%	5%	7%	9%	11%
32	Power Split Hybrid	PSHEV	ELEC	2007	13.90%	13.50%	$ 1,462	$ 1,409	TIME		0.03		TRUE	0%	5%	7%	9%	11%
33	2-Mode Hybrid	2MHEV	ELEC	2007	0.00%	0.00%	$ -	$ -					FALSE	0%	5%	7%	9%	11%
34	Plug-in Hybrid	PHEV	ELEC	2011	60.70%	63.30%	$ 19,701	$ 19,648	VOLUME	150,000	0.2		TRUE	0%	5%	7%	9%	11%
35	Material Substitution (1%)	MS1	MSM	2007	0.00%	0.00%	$ -	$ -					FALSE	5%	15%	30%	65%	80%
36	Material Substitution (2%)	MS2	MSM	2007	0.00%	0.00%	$ -	$ -					FALSE	5%	15%	30%	65%	80%
37	Material Substitution (5%)	MS5	MSM	2007	0.00%	0.00%	$ -	$ -					FALSE	5%	15%	30%	65%	80%
38	Low Rolling Resistance Tires	ROLL	DLR	2007	1.00%	2.00%	$ 6	$ 9			0.03		TRUE	20%	40%	60%	80%	100%
39	Low Drag Brakes	LDB	DLR	2007	0.00%	0.00%	$ -	$ -					FALSE	20%	40%	60%	80%	100%
40	Secondary Axle Disconnect - Unibody	SAXU	DLR	2007	0.00%	0.00%	$ -	$ -					FALSE	17%	25%	42%	65%	100%
41	Secondary Axle Disconnect - Ladder Frame	SAXL	DLR	2007	1.00%	1.50%	$ 117	$ 117	TIME		0.03		TRUE	17%	25%	42%	65%	100%
42	Aero Drag Reduction	AERO	AERO	2007	2.00%	3.00%	$ 60	$ 116	TIME		0.03		TRUE	17%	25%	42%	65%	100%

For each technology, Table 14 contains the following:

Index:	index of the technology, which loosely reflects the sequence to follow when populating technology groups
Technology:	full technology name
Abbr.:	technology abbreviation used in code and output files
TechType:	technology group into which to place technology
Year Avail:	first year the technology is available
FC-Lower:	low-end estimate of the incremental fuel consumption reduction
FC-Upper:	high-end estimate of the incremental fuel consumption reduction
Cost-Lower:	low-end estimate of the incremental cost (RPE in 2003 dollars, or dollars/pound for material substitution)
Cost-Upper:	high-end estimate of the incremental cost (RPE in 2003 dollars, or dollars/pound for material substitution)
Learning Type:	whether to apply time-based or volume-based learning to the technology
Learning Threshold:	if using volume-based learning, the minimum sales volume the industry must reach before learning for the technology begins
Learning Rate:	the rate of decline to apply to the learning curve (time-based and volume-based)
Aux:	for material substitution technologies, the relative change in curb weight; not applicable to other technologies
Applicability:	whether the technology is available for applicability on a given technology class
Phase-In:	maximum incremental share of a manufacturer's fleet to which technology can be added in model years 2011 to 2015; 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 would follow one of the two specified orders: IATC and CVT; or: IATC, 6/7/8-speed auto, and dual clutch / automatic manual transmission (DCTAM).

Appendix D.4.1 Technology Synergies

Technology synergies occur when the combined effect of two technologies is greater than (or less than) the given cost or 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 15 and Table 16, 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 15. Technology Fuel Consumption Synergy Table

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.											
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
PSHEV	DCTAM	-7.00%	-3.90%	-7.20%	-3.90%	-4.10%	-3.40%	-4.10%	-4.30%	-4.10%	-4.00%	-2.10%	0.00%
PHEV	CVT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PHEV	DCTAM	-3.10%	-1.70%	-3.10%	-1.70%	-1.80%	-1.70%	0.00%	0.00%	0.00%	-1.70%	0.00%	0.00%
MHEV	CBRST	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%	-2.10%
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%
TRBDS	DVVLD	-2.00%	-2.00%	-2.00%	0.50%	-2.00%	0.50%	0.50%	0.50%	0.50%	-2.00%	0.50%	0.50%
TRBDS	CVVL	-2.50%	-2.50%	-2.50%	0.20%	-2.50%	0.20%	0.20%	0.20%	0.20%	-2.50%	0.20%	0.20%
TRBDS	DVVLO	1.10%	1.10%	1.10%	-0.90%	1.10%	-0.90%	-0.90%	-0.90%	-0.90%	1.10%	-0.90%	-0.90%
TRBDS	CDOHC	0.80%	0.80%	0.80%	-1.10%	0.80%	-1.10%	-1.10%	-1.10%	-1.10%	0.80%	-1.10%	-1.10%
DSLC	DVVLD	-1.80%	-1.80%	-1.80%	0.40%	-1.80%	0.40%	0.40%	0.40%	0.40%	-1.80%	0.40%	0.40%

Table 16. Technology Cost Synergy Table

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.											
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
PSHEV	DCTAM	$ (91)	$ (241)	$ (91)	$ (241)	$ (241)	$ (241)	$ (241)	$ (541)	$ (241)	$ (241)	$ (541)	$ -
PHEV	CVT	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
PHEV	DCTAM	$ (91)	$ (241)	$ (91)	$ (241)	$ (91)	$ (241)	$ -	$ -	$ -	$ (241)	$ -	$ -
MHEV	CBRST	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)	$ (141)
DEACD	CVVL	$ -	$ -	$ -	$ (71)	$ -	$ (71)	$ (71)	$ (71)	$ (71)	$ -	$ (71)	$ (71)
TRBDS	DVVLD	$ (69)	$ (69)	$ (69)	$ (133)	$ (69)	$ (133)	$ (133)	$ (138)	$ (133)	$ (69)	$ (133)	$ (138)
TRBDS	CVVL	$ (69)	$ (69)	$ (69)	$ (133)	$ (69)	$ (133)	$ (133)	$ (138)	$ (133)	$ (69)	$ (133)	$ (138)
TRBDS	DVVLO	$ 335	$ 335	$ 335	$ 333	$ 335	$ 333	$ 333	$ 576	$ 333	$ 335	$ 333	$ 576
TRBDS	CDOHC	$ (69)	$ (69)	$ (69)	$ (133)	$ (69)	$ (133)	$ (133)	$ (138)	$ (133)	$ (69)	$ (133)	$ (138)
DSLC	DVVLD	$ (61)	$ (61)	$ (61)	$ (122)	$ (61)	$ (122)	$ (122)	$ (122)	$ (122)	$ (61)	$ (122)	$ (122)

The purpose of each column in the synergy table is as follows:

Technology A:	defines one of the technologies involved
Technology B:	defines the second technology involved
Subcompact PC:	contains values to offset the technology fuel consumption or cost when either technology A or B is being applied when the other is already installed
Other Technology Classes:	same as above

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 paired 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 D.5 Scenario Definition

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

Table 17. Regulatory Classes

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

Under the current system, all nonpassenger automobiles with GVW ratings below 8,500 pounds will be assigned to use regulatory class 3. By default, regulatory class 0 includes vehicles with GVW ratings above 8,500 pounds. However, as discussed below, such vehicles can be selectively assigned to use the nonpassenger automobile regulatory class.

Table 18 shows an example of a CAFE scenario definition worksheet. The purpose of each of the defined sections is as follows:

Scenario Description: a short name describing the key features of the scenario

Regulatory Reclassification: specifies whether vehicles from one regulatory class should be merged with vehicles from another regulatory class. Table 19 describes all available merging options. In the example scenario shown in Table 18, "RC1A" code indicates that all vehicles should be merged into the domestic passenger automobiles, regulatory class 1.

Passenger Automobile Standards: the CAFE functional or flat standards to use during modeling of the scenario. The appropriate "Fnc Type" is indicated by entering the corresponding code from Table 20. For example, entering "1" directs the compliance simulation model to apply a flat standard system, whereas entering "2" directs the model to use a logistic area-based functional form. The "Coefficients" sub-section contains corresponding coefficient values. Lastly, the "Alt. Minimum" sub-section applies 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 18 function type "2" is used, indicating that passenger automobiles should use a logistic area-based functional form standard system, 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. The example scenario below

does not provide a standards definition for use with nonpassenger automobiles, since the regulatory declassification section forces all vehicles into RC-1.

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.

Table 18. Scenario Definition Worksheet (Sample)

CAFE Scenario Definition — **Model Year**

Scenario Description		optimized standards				
Regulatory Declassification		**2011**	**2012**	**2013**	**2014**	**2015**
		RC1A	RC1A	RC1A	RC1A	RC1A
Passenger Automobile Standards		**2011**	**2012**	**2013**	**2014**	**2015**
	Fnc Type	2	2	2	2	2
	Coefficients					
	A	34.9	34.2	34.1	34.5	35.9
	B	30.7	30.6	31.0	31.3	31.7
	C	42.3	43.7	43.1	43.3	42.5
	D	2.0	2.1	1.6	2.0	1.0
	Alt. Minimum					
	mpg	27.5	27.5	27.5	27.5	27.5
	% average	92%	92%	92%	92%	92%
Nonpassenger Automobile Standards		**2011**	**2012**	**2013**	**2014**	**2015**
	Fnc Type					
	Coefficients					
	A					
	B					
	C					
	D					
	Alt. Minimum					
	mpg					
	% average					
Comply By Industry		**2011**	**2012**	**2013**	**2014**	**2015**

Table 19. Regulatory Reclassifications

Code	Description
<blank>	do not apply regulatory merging to any classes
RC1	if all passenger automobiles (domestic and imported) should be merged into regulatory class 1
RC1A	if all vehicles (passenger, nonpassenger, and unregulated automobiles) should be merged into regulatory class 1
RC3	if all passenger automobiles (domestic and imported) should be merged into regulatory class 3
RC3D	if all domestic passenger automobiles should be merged into regulatory class 3
RC3I	if all imported passenger automobiles should be merged into

	regulatory class 3
RC3H	if all unregulated vehicles should be merged into regulatory class 3

Table 20. Functional CAFE Standard Specifications

Type	Description	Specification
1	Flat standard A: mpg	$STD_{MY} = A$
2	Logistic area-based function A: mpg ("ceiling") B: mpg ("floor") C: square feet ("midpoint") D: square feet ("width")	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} + \left(\frac{1}{B} - \frac{1}{A} \right) \left(\frac{\exp\left(\frac{AREA_{i,MY} - C}{D} \right)}{1 + \exp\left(\frac{AREA_{i,MY} - C}{D} \right)} \right) \right] \right)}$
3	Exponential area-based function A: mpg ("ceiling") B: mpg (should be >A) C: sq. ft. (determines "height") note: if AREAmin is the lowest possible area, C must not exceed AREAmin/(1-ln(B/A))	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{AREA_{i,MY}}{C} \right) \right] \right)}$
4	Logistic weight-based function A: mpg ("ceiling") B: mpg ("floor") C: pounds ("midpoint") D: pounds ("width')	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} + \left(\frac{1}{B} - \frac{1}{A} \right) \left(\frac{\exp\left(\frac{CW_{i,MY} - C}{D} \right)}{1 + \exp\left(\frac{CW_{i,MY} - C}{D} \right)} \right) \right] \right)}$
5	Exponential weight-based function A: mpg ("ceiling") B: mpg (should be >A) C: pounds (determines "height") note: if CWmin is the lowest possible weight, C must not exceed CWmin/(1-ln(B/A))	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left(SALES_{i,MY} \times \left[\frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{CW_{i,MY}}{C} \right) \right] \right)}$

NOTE: Automated curve fitting and optimization only available for function type 2.

Appendix D.6 Parameters

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

Appendix D.6.1 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 21. Vehicle Age Data

Category	Model Characteristic	Units	Definition/Notes	Source
Vehicle Age Data	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)	

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 D.6.2 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 22. Forecast Data

Category	Model Characteristic	Units	Definition/Notes	Source
Forecast Data	Retail Fuel Prices	$/gallon	2006 $ 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	2006 $ 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	2006 $ 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 D.6.3 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 23 identifies available sources of information for economic values, the system does not require that the user rely on these sources.

Table 23. Economic Values

Category	Model Characteristic	Units	Definition/Notes	Source
Economic Values	Rebound Effect	percent	increase in the annual use of vehicle models in response to 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	OMB (1998), p. 72
	Nitrogen Oxides	$/ton	economic costs arising from Nitrous Oxides damage	
	Particulate Matter	$/ton	economic costs arising from Particulate Matter damage	
	Sulfur Dioxide	$/ton	economic costs arising from Sulfur Oxides damage	
	Carbon Dioxide	$/metric ton	economic costs arising from Carbon Dioxide damage	Volpe estimates
	CO-2 Annual Cost Increase	percent	percent of annual increase in economic costs arising from Carbon Dioxide damage	
	CO-2 Reference Year	model year	the reference year, which the economic costs arising from Carbon Dioxide damage are specified in	

By reducing the cost of gasoline per mile driven, tighter CAFE standards can result in a slight increase in annual miles driven per vehicle. This increase in the annual number of miles each vehicle is driven, referred to as the "rebound effect," also produces a corresponding increase in the *total* number of miles driven by vehicles of each model year during each calendar year they remain in the fleet. The magnitude of the rebound effect from higher fuel economy standards is equal to the negative of the elasticity of vehicle use (measured either per vehicle or for an entire vehicle fleet) with respect to either fuel cost per mile driven (equal to fuel price per gallon divided by miles per gallon) or fuel efficiency itself. (This elasticity has a negative value, so the rebound effect is expressed as a positive value.)

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

Appendix D.6.4 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 24. Fuel Properties

Category	Model Characteristic	Units	Definition/Notes	Source
Fuel Properties	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	
	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 D.6.5 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 25. Upstream Emissions

Category	Model Characteristic	Units	Definition/Notes	Source
Upstream Emissions ***(Total Emissions by Stage of Fuel Production and Distribution)***	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 D.7 Emissions Rates

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.

Table 26. Vehicular Emission Factors (CO shown for gasoline and diesel only)

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

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

Appendix E.1 Overview

The system produces six formatted output files, all as Microsoft Excel workbooks, four of which are for each scenario defined in the compliance model scenarios file, and two cumulative output files covering all scenarios. The system places all files in the "reports" folder, located in the user selected output path, under the session name (ex: **C:\cafe\demo-run\demo\reports**). Table 27 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.[26]

Table 27 Output File Contents

Output File[27]	**Contents**
Industry_Summary_Sn*.xls	industry-wide and manufacturer-specific results, showing all model years per worksheet, for each regulatory class:[28] 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
Manufacturer_Summary_Sn*.xls	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_Summary_Sn*.xls	vehicle model-specific results: index, ID number, manufacturer, model name, nameplate, regulatory class, NRC 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
Effects_Summary_Sn*.xls	national-scale effects: travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions, and economic externalities related to highway travel

[26] 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.

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

[28] As discussed earlier, RC0=unregulated vehicles, RC1=domestic cars, RC2=imported cars, and RC3 =light trucks.

	and petroleum consumption
EA_Report.xls	national-scale effects, for all scenarios, disaggregated by calendar year for each model year: fuel consumption and carbon dioxide and criteria pollutant emissions
ScenSummary_Report.xls	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

The remainder of this section shows sample output files for a scenario based on reformed passenger automobile standards, with a 27.5 mpg flat standard in the baseline scenario. Both scenarios address model years spawning five years (2011-2015), however, only the first and the last years (2011 and 2015) are displayed in most screenshots. Also, both scenarios assume regulatory merging of all vehicles into RC-1 (domestic passenger autos). Furthermore, because the output files produced by the system are extensive, the text shows only portions of some files. Also, although the system produces output specific to each represented vehicle model, only the more summarized output files are shown here.

The file defining the initial state of the fleet for this example—*demo_market_data.xls*—contains fictitious entries for many fields. Therefore, when used with this file, the system will produce fictitious results. Though useful for diagnostic purposes, such results should be treated as otherwise meaningless.

Appendix E.2 Industry-Level Summary

Table 28. Industry-Level Summary (Sample)

Industry Overall		2011 Total			2015 Total		
		Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Total Sales	Unregulated	0	0	- %	0	0	- %
	Dom Auto	2,253,137	0	- %	2,253,137	0	- %
	Imp Auto	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %
	Overall	2,253,137	0	- %	2,253,137	0	- %
Value of Preliminary CAFE Standard	Unregulated	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	31.72	4.22	15%	32.72	5.22	19%
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %
	Overall	31.72	4.22	15%	32.72	5.22	19%
Value of Final CAFE Standard	Unregulated	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	31.72	4.22	15%	32.72	5.22	19%
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %
	Overall	31.72	4.22	15%	32.72	5.22	19%
Average Fuel Economy	Unregulated	0.00	0.00	- %	0.00	0.00	- %
	Dom Auto	30.62	2.40	8%	32.72	4.49	16%
	Imp Auto	0.00	0.00	- %	0.00	0.00	- %
	Light Truck	0.00	0.00	- %	0.00	0.00	- %
	Overall	30.62	2.40	8%	32.72	4.49	16%
Average Curb Weight (lb.)	Unregulated	0	0	- %	0	0	- %
	Dom Auto	3,332	0	- %	3,332	0	- %
	Imp Auto	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %
	Overall	3,332	0	- %	3,332	0	- %
Average Area (sq. ft.)	Unregulated	0	0	- %	0	0	- %
	Dom Auto	46	0	- %	46	0	- %
	Imp Auto	0	0	- %	0	0	- %
	Light Truck	0	0	- %	0	0	- %
	Overall	46	0	- %	46	0	- %
Average Technology Costs (RPE)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 897.49	$ 751.56	515%	$1,423.45	$1,277.52	875%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 897.49	$ 751.56	515%	$1,423.45	$1,277.52	875%
Average Fines Incurred (RPE)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 60.83	$ 60.83	- %	$ -	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 60.83	$ 60.83	- %	$ -	$ -	- %
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 958.32	$ 812.39	557%	$1,423.45	$1,277.52	875%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 958.32	$ 812.39	557%	$1,423.45	$1,277.52	875%
Total Incurred Technology Costs ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$2,022.16	$1,693.36	515%	$3,207.23	$2,878.44	875%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$2,022.16	$1,693.36	515%	$3,207.23	$2,878.44	875%
Total Fines Owed ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$ 137.07	$ 137.07	- %	$ -	$ -	- %
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$ 137.07	$ 137.07	- %	$ -	$ -	- %
Total Increase in Sales Revenue ($m)	Unregulated	$ -	$ -	- %	$ -	$ -	- %
	Dom Auto	$2,159.23	$1,830.43	557%	$3,207.23	$2,878.44	875%
	Imp Auto	$ -	$ -	- %	$ -	$ -	- %
	Light Truck	$ -	$ -	- %	$ -	$ -	- %
	Overall	$2,159.23	$1,830.43	557%	$3,207.23	$2,878.44	875%

Appendix E.3 Manufacturer-Level Summary

Table 29. Manufacturer-Level Summary (Sample)

Manufacturer		ACM		
		Current Scenario	Delta (abs.)	Delta (%)
Total Sales	Unregulated	0	0	- %
	Dom Auto	205,844	0	- %
	Imp Auto	0	0	- %
	Light Truck	0	0	- %
	Overall	205,844	0	- %
Value of Preliminary CAFE Standard	Unregulated	0.00	0.00	- %
	Dom Auto	32.30	4.80	17%
	Imp Auto	0.00	-27.50	(100%)
	Light Truck	0.00	0.00	- %
	Overall	32.30	4.80	17%
Value of Final CAFE Standard	Unregulated	0.00	0.00	- %
	Dom Auto	32.30	4.80	17%
	Imp Auto	0.00	-27.50	(100%)
	Light Truck	0.00	0.00	- %
	Overall	32.30	4.80	17%
Average Fuel Economy	Unregulated	0.00	0.00	- %
	Dom Auto	28.83	1.35	5%
	Imp Auto	0.00	0.00	- %
	Light Truck	0.00	0.00	- %
	Overall	28.83	1.35	5%
Average Curb Weight (lb.)	Unregulated	0	0	- %
	Dom Auto	3,537	0	- %
	Imp Auto	0	0	- %
	Light Truck	0	0	- %
	Overall	3,537	0	- %
Average Area (sq. ft.)	Unregulated	0	0	- %
	Dom Auto	44	0	- %
	Imp Auto	0	0	- %
	Light Truck	0	0	- %
	Overall	44	0	- %
Average Technology Costs (RPE)	Unregulated	$ -	$ -	- %
	Dom Auto	$1,627.35	$1,127.12	225%
	Imp Auto	$ -	$ -	- %
	Light Truck	$ -	$ -	- %
	Overall	$1,627.35	$1,127.12	225%
Average Fines Incurred (RPE)	Unregulated	$ -	$ -	- %
	Dom Auto	$ 192.50	$ 192.50	- %
	Imp Auto	$ -	$ -	- %
	Light Truck	$ -	$ -	- %
	Overall	$ 192.50	$ 192.50	- %
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	Unregulated	$ -	$ -	- %
	Dom Auto	$1,819.85	$1,319.62	264%
	Imp Auto	$ -	$ -	- %
	Light Truck	$ -	$ -	- %
	Overall	$1,819.85	$1,319.62	264%
Total Incurred Technology Costs ($m)	Unregulated	$ -	$ -	- %
	Dom Auto	$ 334.98	$ 232.01	225%
	Imp Auto	$ -	$ -	- %
	Light Truck	$ -	$ -	- %
	Overall	$ 334.98	$ 232.01	225%
Total Fines Owed ($m)	Unregulated	$ -	$ -	- %
	Dom Auto	$ 39.62	$ 39.62	- %
	Imp Auto	$ -	$ -	- %
	Light Truck	$ -	$ -	- %
	Overall	$ 39.62	$ 39.62	- %
Total Increase in Sales Revenue ($m)	Unregulated	$ -	$ -	- %
	Dom Auto	$ 374.60	$ 271.64	264%
	Imp Auto	$ -	$ -	- %
	Light Truck	$ -	$ -	- %
	Overall	$ 374.60	$ 271.64	264%

Appendix F Vehicle-Level Summary

Table 30. Vehicle-Level Summary Contents

Group	Column	Contents
Index		unique vehicle index for the entire industry
ID#		unique vehicle ID per manufacturer
Manufacturer		manufacturer name
Model		model name
Name Plate		nameplate name
Reg Class		regulatory class
Technology Class		vehicle technology class
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 ($)		final MSRP ($)
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
Transmission	ID#	ID number of the vehicle's transmission
	Type	transmission type
Unit ($)	Incurred Tech Cost	unit technology cost ($)
	Price Increase	unit price increase ($)
Total ($k)	Incurred Tech Cost	total technology cost ($)
	Increase in Sales Rev.	total increase in revenue ($)
Redesign State		redesign state of the vehicle
Refresh State		refresh state of the vehicle
Technology Utilization/Applicability		usage of each technology by the vehicle

The summary of effects for each scenario is organized into sections. The first section, shown by example in,Table 31 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 31. Effects Summary—Energy Consumption

Model Year		2011 Total			2015 Total		
		Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Energy Consumption							
Lifetime Fuel Consumption (k gal.)	Gas	14,277,270	-1,444,637	(9%)	13,116,480	-2,605,427	(17%)
	Diesel	373,542	373,542	- %	714,217	714,217	- %
	Total	14,650,812	-1,071,095	(7%)	13,830,697	-1,891,210	(12%)
Sales	Gas	2,190,626	-62,512	(3%)	2,124,056	-129,082	(6%)
	Diesel	62,512	62,512	- %	129,082	129,082	- %
	Total	2,253,137	0	- %	2,253,137	0	- %
Lifetime VMT (k mi.)	Gas	348,808,204	-6,064,678	(2%)	340,974,545	-13,898,336	(4%)
	Diesel	10,160,775	10,160,775	- %	21,097,484	21,097,484	- %
	Total	358,968,979	4,096,097	1%	362,072,029	7,199,148	2%
Average Fuel Economy (mpg)	Gas	30.53	2.32	8%	32.50	4.29	15%
	Diesel	33.99	65,535.00	6553500%	36.90	65,535.00	6553500%
	Total	30.62	2.41	9%	32.72	4.51	16%

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 32. 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 33**Error! Reference source not found.** 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 33. Effects Summary—Emissions

Model Year		2011 Total			2015 Total		
		Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Emissions							
CO2 (mmT)	LDGV	138	-14	(9%)	127	-25	(17%)
	LDDV	4	4	- %	8	8	- %
	LDGT1	0	0	- %	0	0	- %
	LDDT1	0	0	- %	0	0	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	142	-10	(6%)	135	-17	(11%)
CO (tons)	LDGV	5,979,374	-104,775	(2%)	5,774,582	-236,781	(4%)
	LDDV	6,833	6,833	- %	14,038	14,038	- %
	LDGT1	0	0	- %	0	0	- %
	LDDT1	0	0	- %	0	0	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	5,986,206	-97,942	(2%)	5,788,620	-222,743	(4%)
VOC (tons)	LDGV	150,758	-6,058	(4%)	139,759	-11,645	(8%)
	LDDV	740	740	- %	1,491	1,491	- %
	LDGT1	0	0	- %	0	0	- %
	LDDT1	0	0	- %	0	0	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	151,498	-5,318	(3%)	141,250	-10,153	(7%)
NOX (tons)	LDGV	127,476	-5,136	(4%)	119,905	-9,940	(8%)
	LDDV	1,312	1,312	- %	2,558	2,558	- %
	LDGT1	0	0	- %	0	0	- %
	LDDT1	0	0	- %	0	0	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	128,787	-3,824	(3%)	122,463	-7,383	(6%)
PM (tons)	LDGV	7,385	-377	(5%)	7,017	-717	(9%)
	LDDV	245	245	- %	450	450	- %
	LDGT1	0	0	- %	0	0	- %
	LDDT1	0	0	- %	0	0	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	7,629	-133	(2%)	7,467	-267	(3%)
SOX (tons)	LDGV	21,642	-1,971	(8%)	20,036	-3,578	(15%)
	LDDV	547	547	- %	1,051	1,051	- %
	LDGT1	0	0	- %	0	0	- %
	LDDT1	0	0	- %	0	0	- %
	LDGT2	0	0	- %	0	0	- %
	LDDT2	0	0	- %	0	0	- %
	HDGV2b	0	0	- %	0	0	- %
	HDDV2b	0	0	- %	0	0	- %
	Total	22,190	-1,424	(6%)	21,087	-2,527	(11%)

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 efffect"

Refueling Time Value: savings in the value of vehicle occupants' time during refueling

Petroleum Market Externalities: reduction in costs of economic externalities resulting from crude petroleum imports

Congestion Costs: the additional cost of highway congestion from added driving due to the "rebound effect"

Accident Costs: additional injury and damage costs of highway crashes

Emissions Damage Costs: the change in damage costs from air pollutant emissions (by species)

In all cases, these costs and benefits are calculated for the fleet of vehicles sold in each model year over their full useful lives, discounted using the rate specified in the benefits model parameters file, and reported in thousands of constant year-2003 dollars.[29] Section III.C.6 of the primary text discusses these types of costs and benefits in greater detail, and Appendix C (Benefits Model Parameters) discusses corresponding input assumptions.

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

Table 34. Effects Summary—Private and Social Costs and Benefits

Model Year	2011 Total			2015 Total		
	Current Scenario	Delta (abs.)	Delta (%)	Current Scenario	Delta (abs.)	Delta (%)
Undiscounted Owner and Societal Costs (k $)						
Total Lifetime Pretax Fuel Expenditures	29,238,893	-2,066,464	(7%)	27,654,812	-3,625,202	(12%)
Fuel Tax Revenues	5,823,180	-431,832	(7%)	5,324,980	-743,517	(12%)
Travel Value	-268,748	-268,748	- %	-459,608	-459,608	- %
Refueling Time Value	-119,536	-119,536	- %	-211,763	-211,763	- %
Petroleum Market Externalities	5,307,037	-387,988	(7%)	5,009,962	-685,062	(12%)
Congestion Costs	19,240,737	219,551	1%	19,407,061	385,874	2%
Noise Costs	251,278	2,867	1%	253,450	5,039	2%
Accident Costs	8,328,080	95,029	1%	8,400,071	167,020	2%
CO2	445,379	-30,831	(6%)	540,863	-69,468	(11%)
CO	0	0	- %	0	0	- %
VOC	257,547	-9,040	(3%)	240,126	-17,261	(7%)
NOX	515,149	-15,296	(3%)	489,851	-29,531	(6%)
PM	1,281,699	-22,305	(2%)	1,254,481	-44,853	(3%)
SOX	355,036	-22,785	(6%)	337,389	-40,432	(11%)
Discounted Owner and Societal Costs (k $)						
Total Lifetime Pretax Fuel Expenditures	19,879,502	-1,406,137	(7%)	18,563,719	-2,436,179	(12%)
Fuel Tax Revenues	4,003,180	-296,438	(7%)	3,653,405	-509,371	(12%)
Travel Value	-183,047	-183,047	- %	-309,590	-309,590	- %
Refueling Time Value	-81,254	-81,254	- %	-143,945	-143,945	- %
Petroleum Market Externalities	3,607,427	-263,733	(7%)	3,405,492	-465,667	(12%)
Congestion Costs	13,078,777	149,238	1%	13,191,834	262,296	2%
Noise Costs	170,805	1,949	1%	172,281	3,426	2%
Accident Costs	5,660,963	64,596	1%	5,709,898	113,531	2%
CO2	274,067	-18,972	(6%)	332,823	-42,748	(11%)
CO	0	0	- %	0	0	- %
VOC	147,016	-5,723	(4%)	139,333	-10,891	(7%)
NOX	289,832	-9,385	(3%)	278,255	-17,917	(6%)
PM	872,817	-14,533	(2%)	857,724	-27,299	(3%)
SOX	241,334	-15,488	(6%)	229,338	-27,483	(11%)

Table 35. Environmental Assessment Summary (Sample)

Fuel Consumption (k. gal) -- Sn 0, Years 2011 - 2015								
Model	Calendar Years							
Years	2011	2012	2013	2014	2015	2016		Total
2011	1,375,463.85	1,342,592.32	1,305,352.07	1,262,600.58	1,213,996.93	1,159,685.57		15,721,906.42
2012		1,375,463.85	1,342,592.32	1,305,352.07	1,262,600.58	1,213,996.93		15,721,906.42
2013			1,375,463.85	1,342,592.32	1,305,352.07	1,262,600.58	...	15,721,906.42
2014				1,375,463.85	1,342,592.32	1,305,352.07		15,721,906.42
2015					1,375,463.85	1,342,592.32		15,721,906.42
Total	1,375,463.85	2,718,056.17	4,023,408.24	5,286,008.82	6,500,005.75	6,284,227.47		

Fuel Consumption (k. gal) -- Sn 1, Years 2011 - 2015								
Model	Calendar Years							
Years	2011	2012	2013	2014	2015	2016		Total
2011	1,407,216.29	1,373,585.93	1,335,485.98	1,291,747.58	1,242,021.92	1,186,456.79		16,084,844.98
2012		1,407,216.29	1,373,585.93	1,335,485.98	1,291,747.58	1,242,021.92		16,084,844.98
2013			1,407,216.29	1,373,585.93	1,335,485.98	1,291,747.58	...	16,084,844.98
2014				1,407,216.29	1,373,585.93	1,335,485.98		16,084,844.98
2015					1,407,216.29	1,373,585.93		16,084,844.98
Total	1,407,216.29	2,780,802.22	4,116,288.20	5,408,035.78	6,650,057.70	6,429,298.20		

Fuel Consumption (k. gal) -- Sn 2, Years 2011 - 2015								
Model	Calendar Years							
Years	2011	2012	2013	2014	2015	2016		Total
2011	1,281,756.89	1,251,124.82	1,216,421.65	1,176,582.71	1,131,290.31	1,080,679.06		14,650,811.71
2012		1,260,239.59	1,230,121.75	1,196,001.16	1,156,831.01	1,112,298.95		14,404,863.46
2013			1,237,292.34	1,207,722.91	1,174,223.60	1,135,766.69	...	14,142,570.47
2014				1,222,806.32	1,193,583.08	1,160,475.98		13,976,991.53
2015					1,210,007.43	1,181,090.06		13,830,696.85
Total	1,281,756.89	2,511,364.41	3,683,835.75	4,803,113.10	5,865,935.44	5,670,310.74		

Fuel Consumption (k. gal) -- Sn 3, Years 2011 - 2015								
Model	Calendar Years							
Years	2011	2012	2013	2014	2015	2016		Total
2011	1,281,756.89	1,251,124.82	1,216,421.65	1,176,582.71	1,131,290.31	1,080,679.06		14,650,811.71
2012		1,260,239.59	1,230,121.75	1,196,001.16	1,156,831.01	1,112,298.95		14,404,863.46
2013			1,241,252.87	1,211,588.78	1,177,982.25	1,139,402.23	...	14,187,840.27
2014				1,228,050.99	1,198,702.41	1,165,453.31		14,036,939.45
2015					1,210,059.80	1,181,141.18		13,831,295.48
Total	1,281,756.89	2,511,364.41	3,687,796.27	4,812,223.64	5,874,865.78	5,678,974.74		

Appendix F.3 Scenario-Level Summary

Table 36. Scenario-Level Summary (Sample)

Total Costs ($M) and Benefits																		
Manufacturer	Product Plans (Do-Nothing Standard)						Optimized Standards						Optimized With Transform & Backstop					
	2011	2012	2013	2014	2015	Total	2011	2012	2013	2014	2015	Total	2011	2012	2013	2014	2015	Total
ACM	-103	-103	-103	-103	-103	-515	232	308	517	533	587	2,176	232	308	517	533	587	2,176
AJA	-226	-226	-226	-226	-226	-1,129	886	1,281	1,525	1,564	1,618	6,874	886	1,281	1,424	1,492	1,580	6,662
EUR	0	0	0	0	0	0	575	575	581	646	673	3,051	575	575	575	621	672	3,020
Big-3 Summary																		
Total	-329	-329	-329	-329	-329	-1,644	1,693	2,164	2,623	2,743	2,878	12,101	1,693	2,164	2,516	2,645	2,839	11,858
Fuel Savings (BG)	-0.363	-0.363	-0.363	-0.363	-0.363	-1.815	1.071	1.317	1.579	1.745	1.891	7.604	1.071	1.317	1.534	1.685	1.891	7.498
Preliminary Standard (MPG)	1.0	1.0	1.0	1.0	1.0		31.7	31.8	31.9	32.3	32.7		31.7	31.7	31.7	32.2	32.7	
Final Standard (MPG)	1.0	1.0	1.0	1.0	1.0		31.7	31.8	31.9	32.3	32.7		31.7	31.7	31.7	32.2	32.7	
Total Benefits	-626	-621	-619	-619	-620	-3,104	1,782	2,179	2,576	2,852	3,102	12,492	1,782	2,179	2,500	2,753	3,102	12,315
Net Benefits	-297	-292	-290	-290	-291	-1,460	89	15	-47	110	224	391	89	15	-16	107	262	458
Benefit:Cost Ratio	1.90	1.89	1.88	1.88	1.89	1.89	1.05	1.01	0.98	1.04	1.08	1.03	1.05	1.01	0.99	1.04	1.09	1.04
Entire Industry Summary																		
Total	-329	-329	-329	-329	-329	-1,644	1,693	2,164	2,623	2,743	2,878	12,101	1,693	2,164	2,516	2,645	2,839	11,858
Fuel Savings (BG)	-0.363	-0.363	-0.363	-0.363	-0.363	-1.815	1.071	1.317	1.579	1.745	1.891	7.604	1.071	1.317	1.534	1.685	1.891	7.498
Preliminary Standard (MPG)	1.0	1.0	1.0	1.0	1.0		31.7	31.8	31.9	32.3	32.7		31.7	31.7	31.7	32.2	32.7	
Final Standard (MPG)	1.0	1.0	1.0	1.0	1.0		31.7	31.8	31.9	32.3	32.7		31.7	31.7	31.7	32.2	32.7	
Total Benefits	-626	-621	-619	-619	-620	-3,104	1,782	2,179	2,576	2,852	3,102	12,492	1,782	2,179	2,500	2,753	3,102	12,315
Net Benefits	-297	-292	-290	-290	-291	-1,460	89	15	-47	110	224	391	89	15	-16	107	262	458
Benefit:Cost Ratio	1.90	1.89	1.88	1.88	1.89	1.89	1.05	1.01	0.98	1.04	1.08	1.03	1.05	1.01	0.99	1.04	1.09	1.04

Average Vehicle Price Increases																		
Manufacturer	Product Plans (Do-Nothing Standard)						Optimized Standards						Optimized With Transform & Backstop					
	2011	2012	2013	2014	2015		2011	2012	2013	2014	2015		2011	2012	2013	2014	2015	
ACM	-500	-500	-500	-500	-500		1,320	1,611	2,510	2,587	2,851		1,320	1,611	2,510	2,587	2,851	
AJA	-229	-229	-229	-229	-229		999	1,351	1,549	1,589	1,644		999	1,345	1,446	1,515	1,605	
EUR	0	0	0	0	0		541	541	547	608	633		541	541	541	584	632	
Average	-146	-146	-146	-146	-146		812	993	1,164	1,217	1,278		812	990	1,117	1,174	1,260	

The CAFE Model 2008 contains algorithms that can be used to develop the "shape" of an attribute-based standard, and, preserving that shape, find the stringency that satisfies specified criteria.[30] Also, in the model and this documentation, the term "optimize" is used to refer generically to estimating the stringency at which a given condition is met. This could include estimating the stringency at which net societal benefits are maximized, but could also refer to estimating the stringency at which any of the following conditions are satisfied: total costs are equal to total benefits, total costs reach a predetermined level, or average required fuel economy reaches a predetermined level. Although the system defaults to the maximization of net benefits, it provides the ability to perform any of these other types of "optimization".

The Optimization Model begins by examining a baseline scenario and aggregating the baseline costs and benefits for the industry.[31] From there, each manufacturer is examined independently to obtain the optimized manufacturer-specific flat (*i.e.*, not attribute-based) standard, for every model year. As the last step of optimization, the model calibrates and fits a reformed (*i.e.*, attribute-based) shape to the manufacturer-optimized fleet from each year, and adjusts the shape to attain the optimum reformed functional standard for the industry.

The Optimization Model has a set of typical runtime options that define the range for optimization and configure the basic behavior of the model. To add flexibility to the model and to support the various considerations of the analysis, the Optimization Model can further be customized via the supplemental runtime options, which alter the model behavior and vary the results. For example, by setting several of the extended runtime options, the model can be configured to use a predefined functional shape, thereby bypassing the manufacturer-specific optimization, and to backstop the target function, which prevents the functional shapes from crossing between subsequent years. Setting the additional options provides the means to smooth the results and enforce consistency between model years being examined. The text in the following sections assumes unconstrained optimization. Also, an example provided in the *Operation* section described below outlines a procedure to set up an optimization run using unconstrained optimization, with demo market and input data files.

Appendix G.1.1 Manufacturer-specific Optimization

During manufacturer-specific optimization, the socially-optimized flat-standards are determined for each manufacturer, and for each year, by varying the level of the required CAFE standard between a user-provided minimum and maximum values, at a specified

[30] Analysis supporting NHTSA's 2009 Final Rule regarding CAFE standards for MY 2011 light vehicles relied only on the stringency-estimating algorithms. The manufacturer-level optimization and statistical curve fitting capabilities documented in this section were not applied for this analysis.

[31] During optimization modeling, even though all of the manufacturers in the industry are examined, only the ones selected for optimization are considered for costs and benefits calculations. Therefore, during optimization, the term "entire industry" refers to the set of manufacturers included in the optimization process.

increment. 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 fleet using the optimized flat-standards specific to each manufacturer, then carries the costs and improvements into the next year.

As the flat-standards are being varied, the system examines new iterations, or trials, performing typical compliance modeling to determine the state of the fleet at the currently selected flat-standard. At the end of each iteration, the model calculates and saves the final technology costs, benefits, fuel savings, and benefit:cost ratios for each manufacturer.

Once all iterations have been processed, the modeling system calculates the optimized flat-standard for each manufacturer. This is achieved by finding the first iteration that yields the maximum net benefits (or some other level) and setting the relevant standard as the optimum for the manufacturer. The entire industry is then re-examined, for the model year, using manufacturer-specific flat-standards, and the optimized fleet is obtained.

Appendix G.1.2 Industry-specific Optimization

The optimized fleet resulting from manufacturer-specific optimization is used to develop the initial functional shape, for each year, based on the following logistic area-based function:

$$T = \left(\frac{1}{A} + \left(\frac{1}{B} - \frac{1}{A} \right) \times \frac{e^{(x-C)/D}}{1 + e^{(x-C)/D}} \right)^{-1} \qquad (29)$$

In equation (29), x is the vehicle footprint and T is the corresponding fuel economy target. Values of C and D are calibrated through statistical analysis (minimum absolute deviation), with A and B, which serve as the lower and upper asymptotes, being fixed during calibration. Values of A and B, however, are determined prior to calibration of C and D by examining n% of the fleet with the smallest footprint for A, and m% of the fleet with the largest footprint for B. The following equations are used when the values for A and B are obtained[32]:

$$p = \lceil N \times (n, m) \rceil \qquad (30)$$

$$A, B = \frac{p + \sum_{q=1, i=p}^{N, x_{i-1}=x_i} q}{\left(\sum_{i=0}^{p} \frac{1}{FE_i} \right) + \left(\sum_{i=p}^{N, x_{i-1}=x_i} \frac{1}{FE_i} \right)} \qquad (31)$$

In the equation (30), N specifies the total number of vehicle models being calibrated, n and m are percent of the fleet with the smallest and largest footprint, and p is the resultant number of vehicle models to consider when calculating the A and B asymptotes. For equation (31), when calculating the A and B coefficients, the model year fleet is assumed

[32] The equation provided for obtaining the A and B asymptotes is based on unweighted calibration and relies on the total number of vehicle models in a fleet for any given model year.

to be sorted by the vehicle footprint (represented by x), in ascending order for A, and in descending order for B. Here, FE represents the vehicle fuel economy of the optimized fleet being aggregated, p is the number of vehicles to examine, as obtained from the first equation, and x is the vehicle footprint.

Once the functional shape has been calibrated, the industry-specific optimization begins. During this stage, the socially-optimized reformed functional shape is determined for the entire industry, and for each year, by adjusting the A and B asymptotes at a user-specified increment, for a given number of iterations above and below the initial calibrated shape. From here on, the process of optimizing the entire industry is very similar to optimizing each manufacturer individually. As with manufacturer-specific optimization, the model years are optimized sequentially, to ensure the correct "carry-over" of technology costs and improvements. At the end of each model year, the system re-runs the entire fleet using the optimized reformed shape, then carries the costs and improvements into the next year.

With the varying A and B asymptotes, the system examines new iterations, performing typical compliance modeling, holding the functional shape constant while altering the stringency. At the end of each iteration, the model calculates and saves the final technology costs, fines owed, benefits, and fuel savings for each manufacturer and industry overall, as well as benefit:cost ratios for the entire industry. Once all iterations have been processed, the modeling system calculates the optimized reformed shape by finding the first iteration with the maximum net benefits. The last step of the optimization process is to use industry-optimized shape to obtain the optimum fleet for the model year.

Appendix G.2 Additional Optimization Settings

The above sections provided an overview of optimization modeling, assuming unconstrained optimization. This section gives a brief overview of some additional notable options available during optimization.

- ***Optimization Modes ("Optimize using")***: When determining the socially-optimized reformed functional shape for a model year being optimized, the modeling system can be configured to use the "Maximum Net Benefits (NB)" approach or the "Maximum Technology (Zero NB)" approach. The former is the default and is described above. The latter is only applicable to industry-specific optimization and works by first obtaining the iteration where net benefits are maximized. From there, the system continues to search for more stringent iterations, as long as the net benefits are above zero (0). As the end result, the optimized functional shape with net benefits closest to zero is obtained, such that the optimized shape is at the least as stringent as the shape produced by the "Maximum Net Benefits" approach.
- ***Use functional form shape defined in the scenarios file***: To use this option, the scenarios file must be set up to contain a valid reformed functional shape in the "Optimization Definition" scenario (#3), and the appropriate option selected in the CAFE Model user interface. Selecting this option will skip manufacturer-specific optimization, and will not calibrate the functional shape as described in the first half of the *Industry-specific Optimization* section. Aside from that, the optimization process remains unchanged.
- ***Backstop the target function***: When the system calibrates the initial functional shape, and later determines the optimum level, there is a possibility that the resulting reformed shapes from multiple model years may cross at one or more points on the curve. The "backstop" option prevents this by reverting to using the reformed functional shape from the previous model year, and re-optimizing. If the optimized shapes are the same for the year being examined and the last model year – that is, the C and D coefficients are the same – the modeling system adjust the A and B asymptotes such that the later year is at the least as stringent as the previous year. The "Backstop Target Function" option is only applicable to industry-specific optimization.

Appendix G.3 Operation for Running Optimization Scenarios

Appendix G.3.1 Create a New Session For Optimization

Step 1: Repeat the procedure for creating a new session as specified in Appendix B.2 – Appendix C.

- When selecting the Compliance Model to use, be sure to select the "CAFE Automated Optimization Model" option.

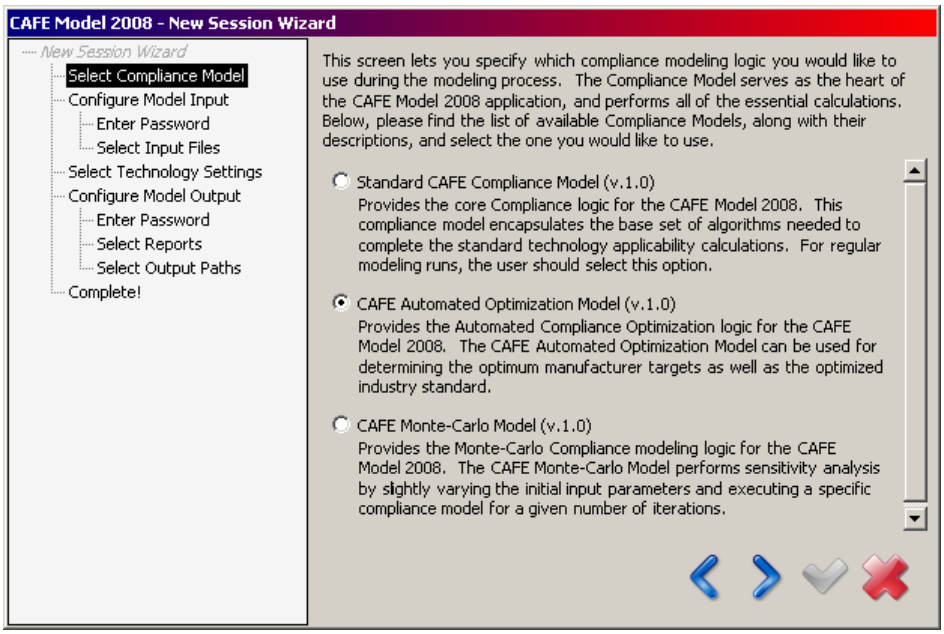

Figure 36. Selecting Optimization Model

- On the Select Input Files screen, remember to select the scenarios file configured for optimization. Then, complete the New Session Wizard by entering a session name and clicking the apply button ( ) (Figure 37).

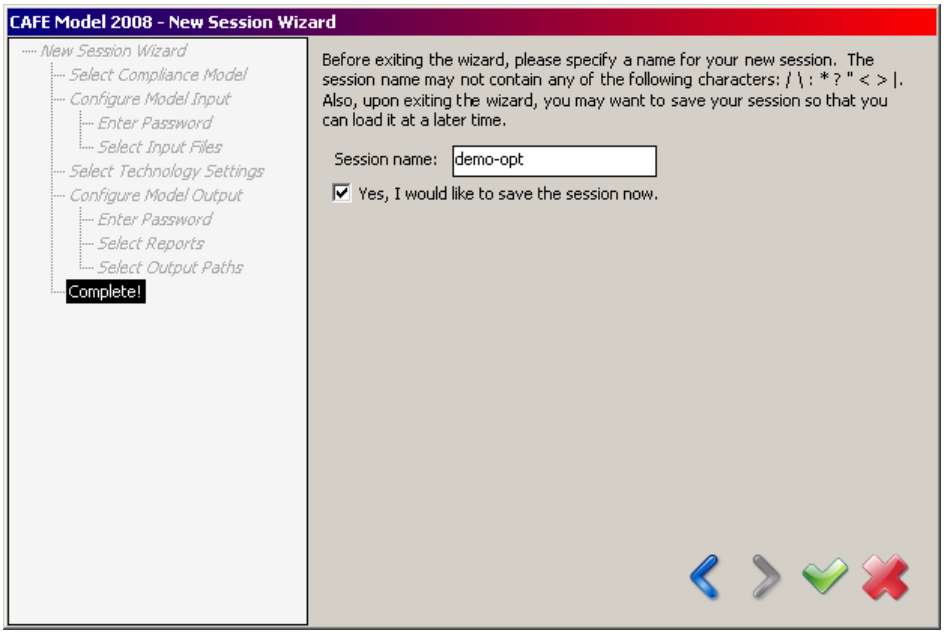

Figure 37. Saving the Optimization Session

- To configure modeling options specific to optimization, select **Tools** > **Modeling Settings**, press **Ctrl+T**, or click on the configure modeling settings button ( ). From there, go to ***Modeling Settings*** > ***Optimization Settings*** **(**Figure 38**)**.
- Select whether you want to optimize automobiles or light trucks, optimize using maximum net benefits or maximum technologies, and the desired calibration settings. Click the next button to continue.

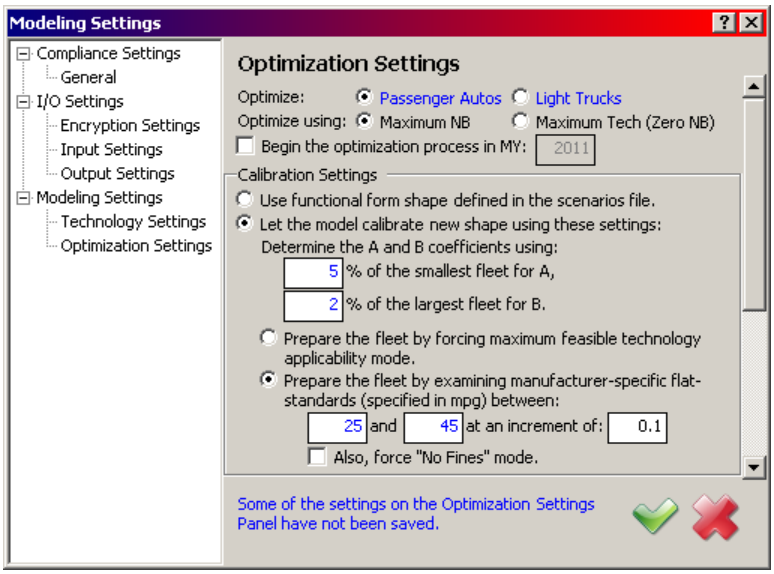

Figure 38. Optimization Settings Window

- Configure the model for industry optimization by selecting the range of iterations to examine above and beyond the manufacturer-optimized level, the increment between iterations, and whether to backstop the target function (Figure 39). Click the next button to continue.

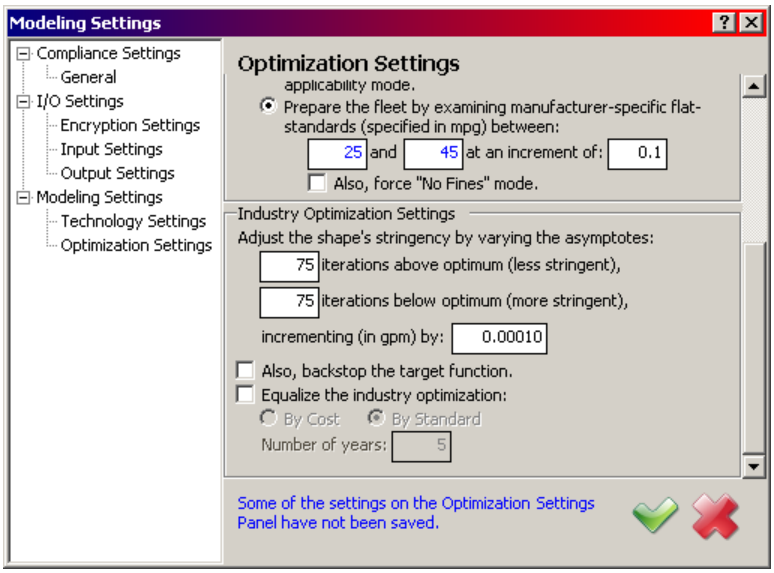

Figure 39. Industry Optimization Settings

- Save the modified settings by clicking the apply button ( ).

Appendix G.3.2 Starting The Optimization Modeling

Step 2: Return to main control window and start the optimization modeling.

- Select **File** > **Start Modeling**, press **Ctrl+M**, or click the start modeling button ( ) (Figure 40).

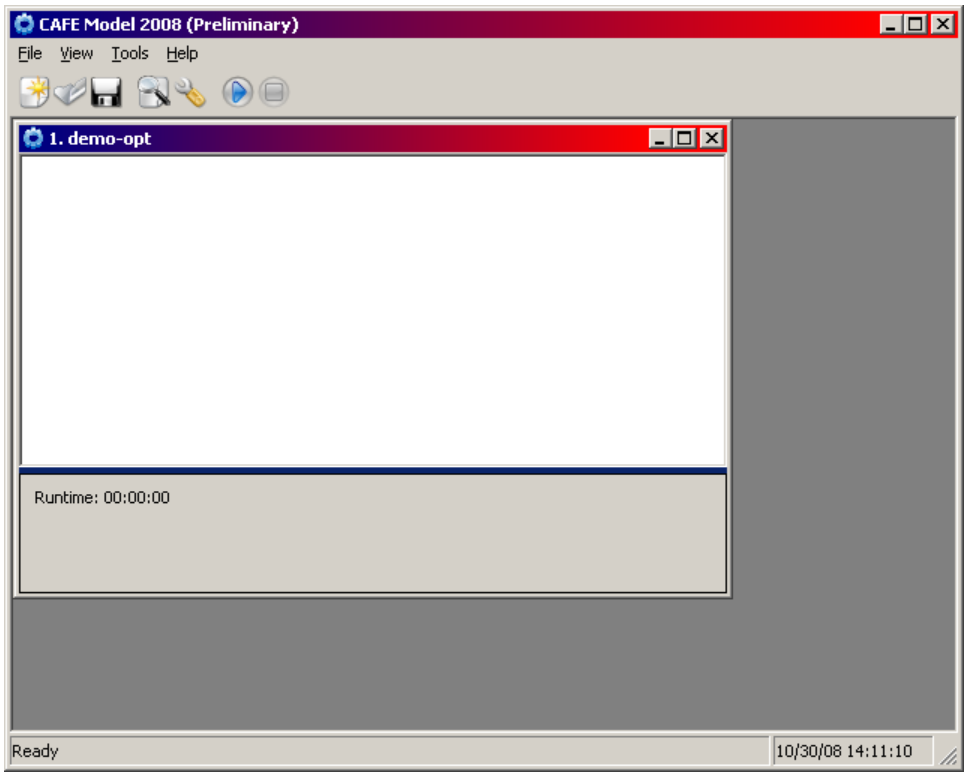

Figure 40. Starting The Optimization Modeling

- While the compliance modeling process is running, the model displays various progress information in the session body, as well as the current iteration being examined at the bottom of the window (Figure 41).

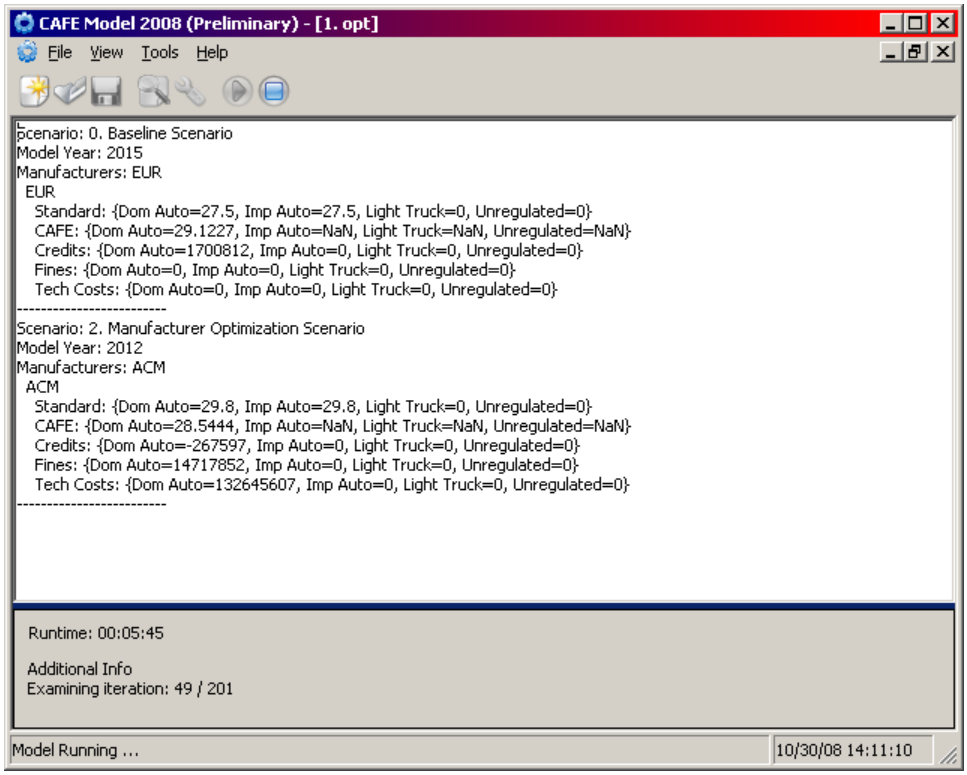

Figure 41. Optimization Session in Progress

- The optimization modeling process has concluded when “Modeling Completed!” appears at the bottom of the main control window (Figure 42).

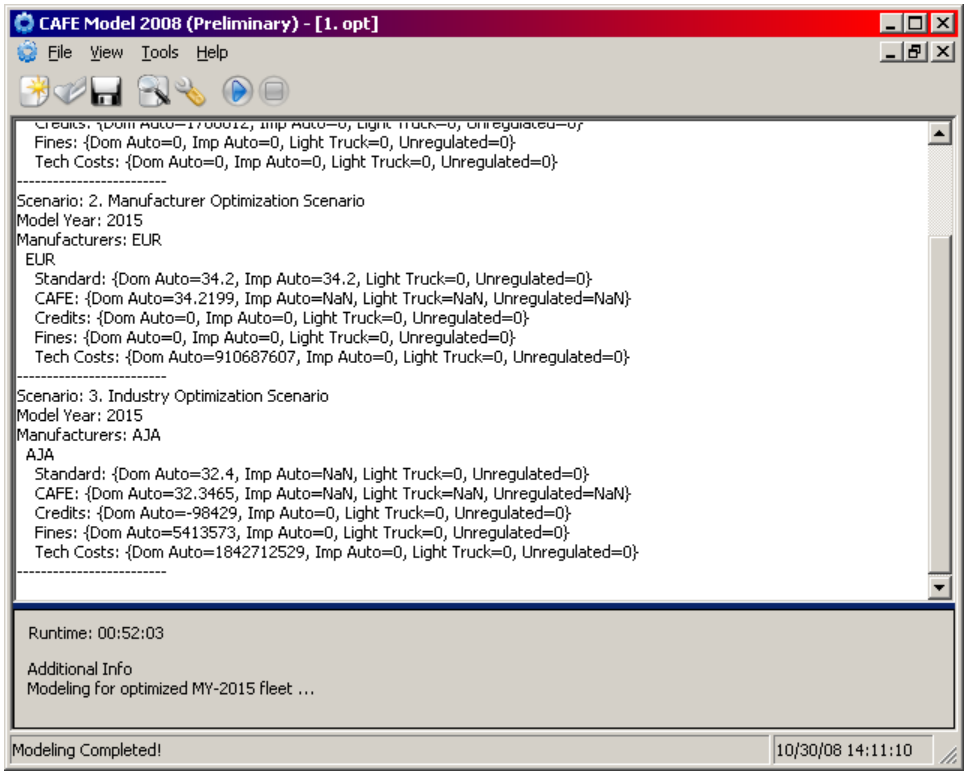

Figure 42. Optimization Session Completed

Appendix G.3.3 Generating Reports For Optimization

Step 3: Generate the modeling reports.

- To review the modeling reports selected for output, select **Tools** > **Manage Output** or press **Ctrl+U (**Figure 43**)**.

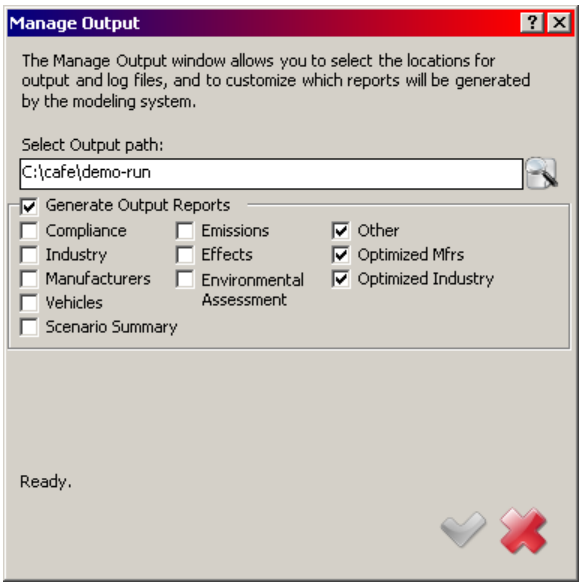

Figure 43. Manage Output Window for Selecting Output Reports

- Select the desired reports, click save ( ), then close ( ).

- Generate the modeling reports by selecting **File > Generate Reports** or pressing **Ctrl+R**.

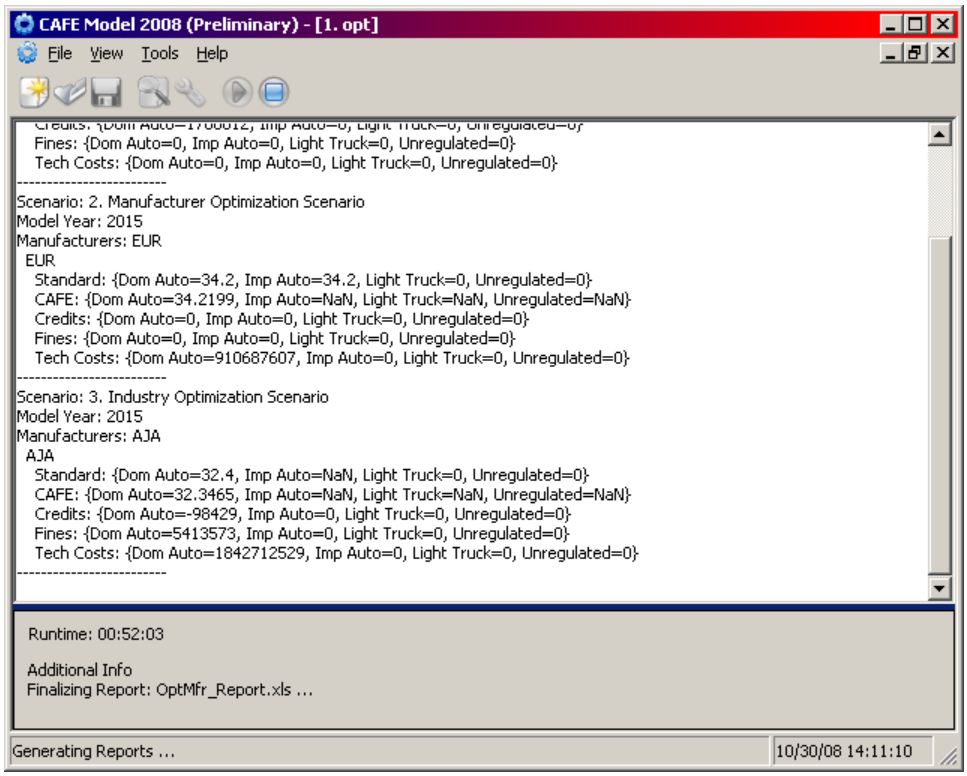

Figure 44. Generate Reports for Optimization

- Wait for "Reporting Completed!" to appear at the bottom of the main control window.

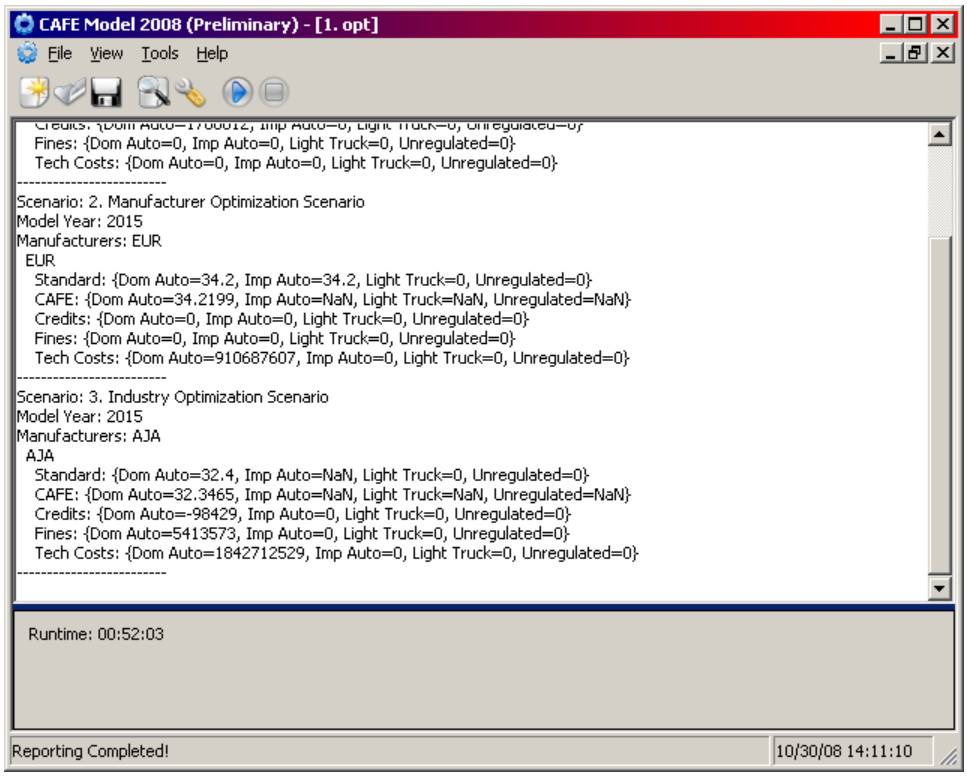

Figure 45. Optimization Report Generation Complete

Appendix G.3.4 Exiting the CAFE Modeling Application

Step 4: Exit the CAFE modeling application.

- Select **File** > **Exit**, press **Alt+F4**, or click the close button (**X**) at the top-right corner of the main control window.
- A "Save Session?" dialog will appear. You may press **Yes**, to save the session, or **No** (recommended), to discard saving the session (Figure 46).

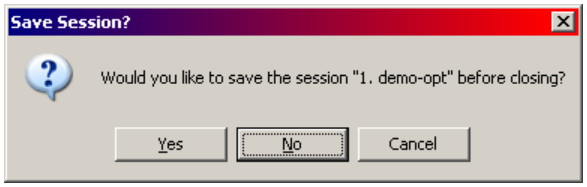

Figure 46. Save Optimization Session Before Closing

Appendix G.3.5 Viewing Results

Step 5: View results by opening appropriate output files.

The model saves all log files to the output folder specified in **Appendix B, Step 3**, organized by the session name. Similarly to the regular modeling runs, the model generates formatted Excel reports during optimization, which are saved in the ***reports*** folder (Figure 47). In the example session created in **Step 1 (Appendix G.3.1)**, the optimization reports will be located under **C:\cafe\demo-run\demo-opt\reports**.

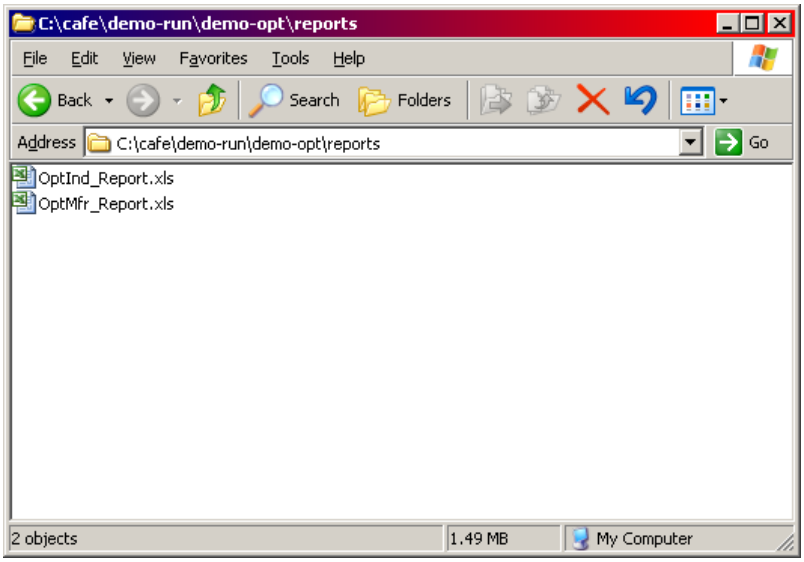

Figure 47. View Optimization Results

All of the standard compliance and effects reports (not shown in the screenshot above) can be generated when running the optimization modeling. Aside from those, the system produces two additional optimization specific reports – one based on manufacturer optimization and one based on industry optimization – which cover all iterations examined by the model.

- *OptMfr_Report.xls*: Manufacturer-level technology costs, benefits, fuel savings, and benefit:cost ratios, for all iterations from manufacturer-specific optimization. This report also contains the socially optimized level for each manufacturer by model year, and benefit:cost, marginal benefit:cost, and net benefits charts.
- *OptInd_Report.xls*: Manufacturer- and industry-level technology costs, fines, benefits, fuel savings, and benefit:cost ratios, for all iterations from industry-specific optimization. This report also provides the socially optimized functional form (aka, optimized shape) for the entire industry by model year, and benefit:cost, marginal benefit:cost, net benefits, and optimized shape charts.

Appendix H Appendix F. Monte Carlo Analysis

Appendix H.1 Overview

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

Appendix H.2 Operation

Appendix H.2.1 Step 1: Setup

Repeat the procedure for creating a new session as specified in Appendix B.

- When selecting the Compliance Model you would like to use, be sure to select the "CAFE Monte-Carlo Model" option.

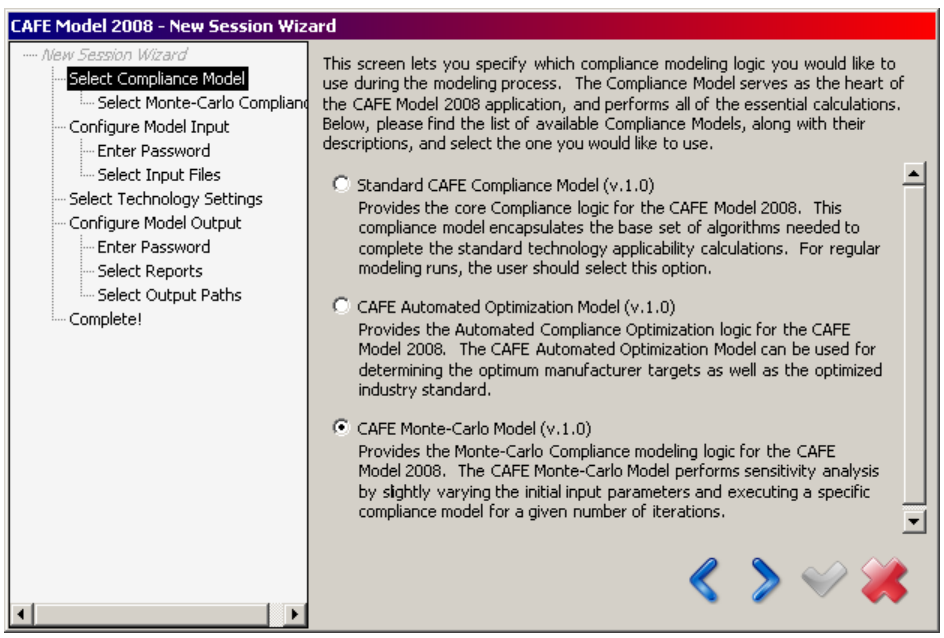

Figure 48. Selecting Monte-Carlo Modeling Option

- On the following screen, make sure that the "Standard CAFE Compliance Model" option is selected.

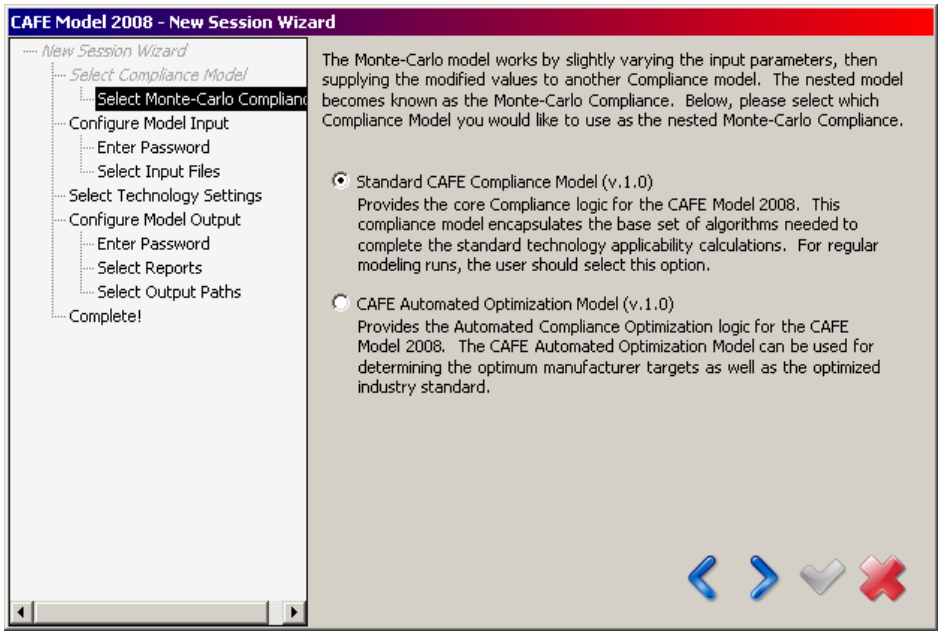

Figure 49. Monte-Carlo Screen Two

- Proceed as in **Appendix B, Step 2** to the end of the wizard. On the Select Input Files screen, remember to select the appropriate files configured for Monte-Carlo. Then, complete the New Session Wizard by entering a session name and clicking the apply button ( ).

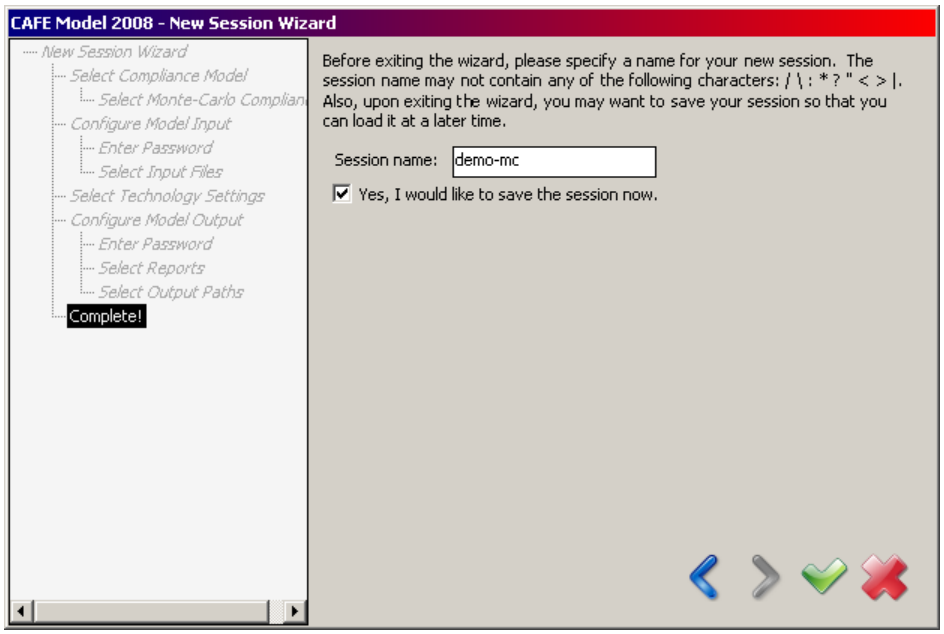

Figure 50. Naming the Monte-Carlo Session

- To configure modeling options specific to Monte-Carlo analysis, select **Tools** > **Modeling Settings**, press **Ctrl+T**, or click on the configure modeling settings button ( ). From there, go to ***Modeling Settings*** > ***Monte-Carlo Settings***.
- Select whether to auto-generate new Monte-Carlo trial pairs or use a pre-existing trials file. If auto-generating new trials, specify the number of trial pairs you wish to generate. Keep in mind that each trial pair consists of two ore more Monte-Carlo trials—one using the default discount rate, and one or more using the alternative discount rates, which are specified in the Monte-Carlo tab of the parameters file. Click the next button to continue.

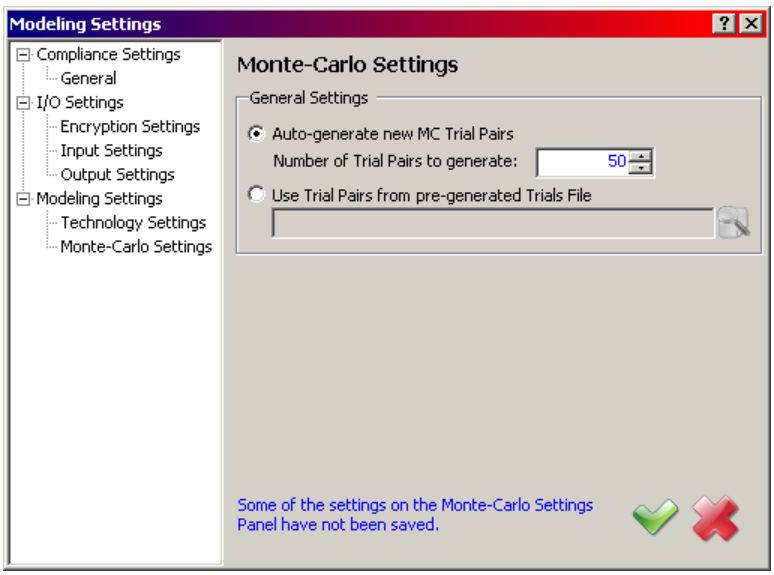

Figure 51. Monte-Carlo Settings Window

- Save the modified settings by clicking the apply button ( ).

Appendix H.2.2 Step 2: Running

Return to main control window and start the Monte-Carlo modeling.

- Select **File > Start Modeling**, press **Ctrl+M**, or click the start modeling button ( ).

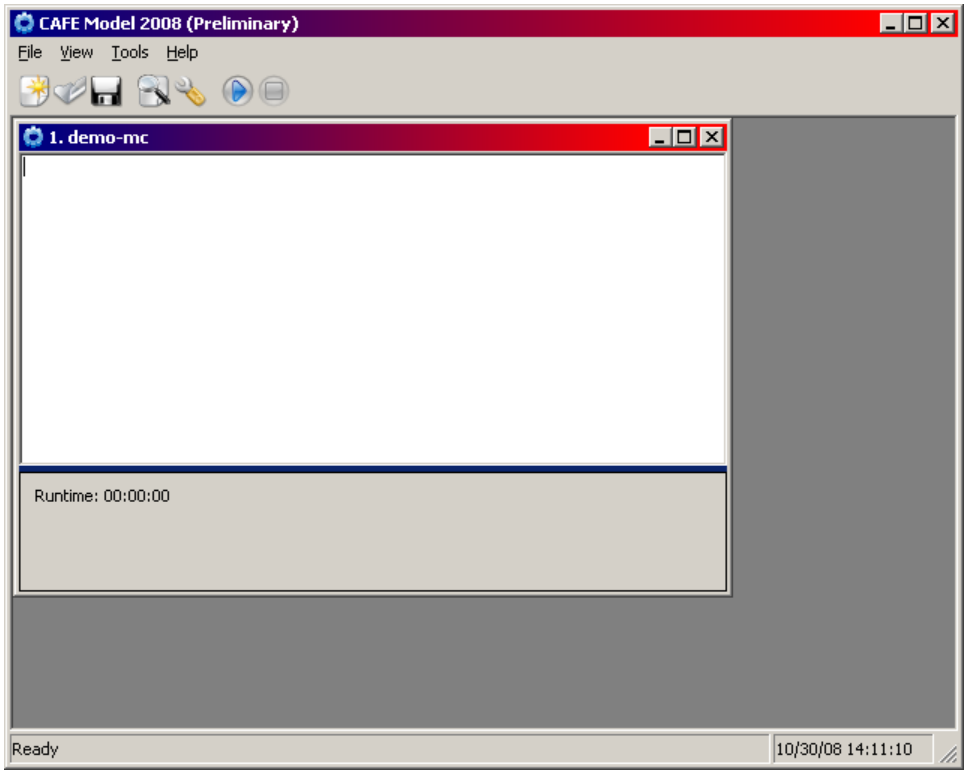

Figure 52. Start Monte-Carlo Modeling

- While the compliance modeling process is running, the model displays various progress information in the session body. During Monte-Carlo, the model also displays additional information, toward the bottom of the window, which includes the current trial being examined, the number of trials examined thus far, and the approximate time until completion.

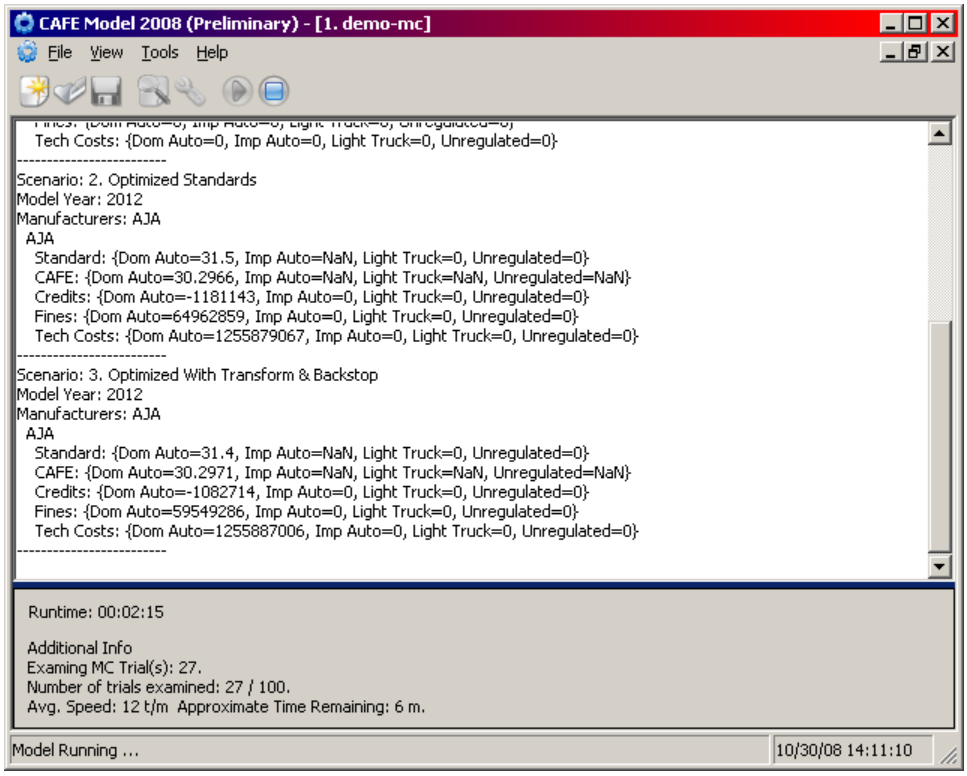

Figure 53. Monte-Carlo Modeling Running

- Once Monte-Carlo processing completes, the model will prompt to generate the Monte-Carlo log files (Figure 54). The model does not support formatted Excel reports when operating in Monte-Carlo mode. Therefore, it is recommended that the log files be generated at this point.

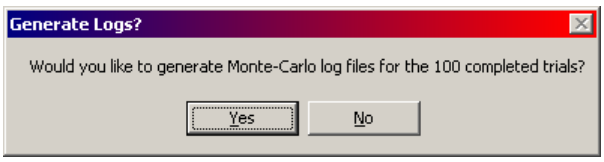

Figure 54 Generate Monte-Carlo Log File Prompt

- The modeling process and generating of Monte-Carlo log files has concluded when "Modeling Completed!" appears at the bottom of the main control window (Figure 55).

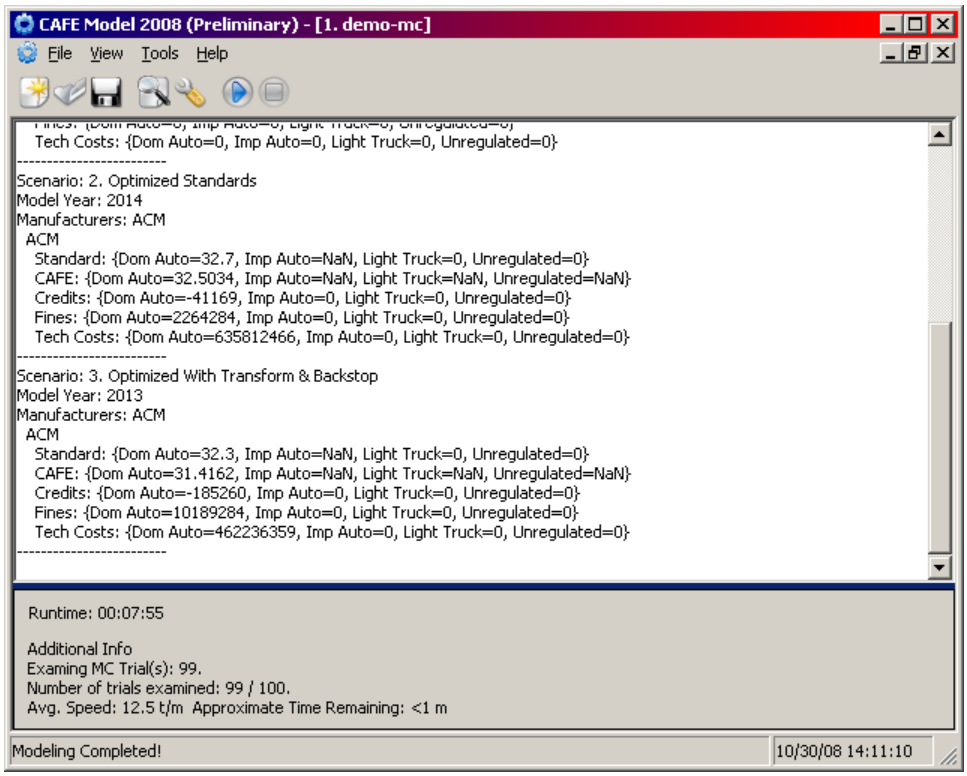

Figure 55 Modeling Completed in Monte-Carlo Mode

Appendix H.2.3 Step 3: Exiting The CAFE Modelling Application

- Select **File > Exit**, press **Alt+F4**, or click the close button (**X**) at the top-right corner of the main control window.
- A "Save Session?" dialog will appear. You may press **Yes**, to save the session, or **No** (recommended), to discard saving the session.

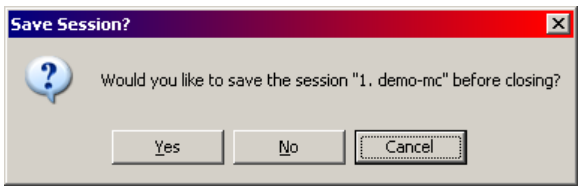

Figure 56. Exiting Monte-Carlo Modeling

Appendix H.2.4 Step 4: View Results

View results by opening appropriate log files.

The model saves all log files to the output folder specified in **Step 1**, organized by the session name. The Monte-Carlo log files are saved in the ***MC-logs*** folder. In the example session created in **Step 1**, the log files will be located under **C:\cafe\demo-run\demo-mc\MC-logs**.

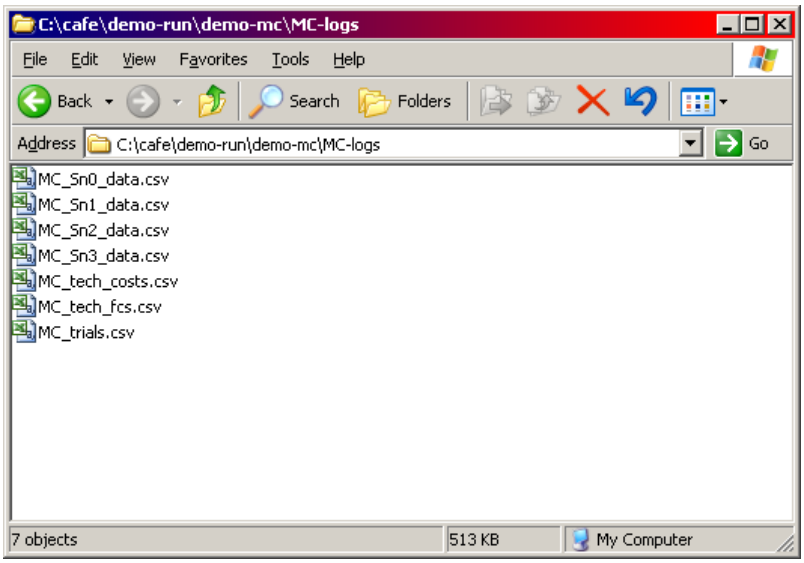

Figure 57. Monte-Carlo Results Folder

As with regular modeling runs, 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 sensitivity analysis. The contents of the file are summarized in Table 37.
- *MC_tech_costs.csv*: Specifies the sales-weighted average technology costs for each technology, adjusted by the randomized cost scales from *MC_trials.csv*. The average costs for a technology are computed across all vehicle technology classes that were used during modeling as follows: $TECHCOST_t = \left(\frac{\sum_{i,MY} \left(SALES_i \times COST_{i,t} \right)}{\sum_{i,MY} SALES_i} \right) \times SCALE_t$, 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 by how much 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 *MC_trials.csv*. The average fuel consumption improvements for a technology are computed across all vehicle technology classes that were used during modeling as follows:

$$TECHFC_t = \left(\frac{\sum_{i,MY} \left(SALES_i \times FC_{i,t} \right)}{\sum_{i,MY} SALES_i} \right) \times SCALE_t$$, 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 by how much 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 (1+) contain changes compared to the baseline. The contents of the file are summarized in Table 38.

Table 37. MC_Trials.csv Contents

Column	Contents
Index	unique index for the trial
FuelPriceEstimates	randomized pretax fuel prices -- the probabilities are: 50% for average fuel prices and 25% for low and high prices
DiscountRate	value of the discount rate examined with each trial
ReboundEffect	randomized value of the rebound effect
MonopsonyCost	randomized value of the monopsony cost
PriceShockCost	randomized value of the price shock cost
MilitarySecurityCost	randomized value of the military security cost
TotalEconomicCosts	randomized value of the total economic costs (not used)
CO2Costs	randomized value of the carbon dioxide costs
Cost(Technology)	randomized value specifying by how much to scale the technology costs of each technology
FC(Technology)	randomized value specifying by how much to scale the technology fuel consumption improvement of each technology

Table 38. MC_SN*_data.csv Contents

Column	Contents
Index	unique index for the trial
DiscountRate	value of the discount rate examined with the current trial
AvePrice_MFR*(MY)	average regulatory costs accumulated by the manufacturer, for each model year
TechCost_MFR*(MY)	total technology costs accumulated by the manufacturer, 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 year
BCRatio(MY)	ratio of social benefits to total technology costs for each model year

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

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