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The Volpe National Transportation Systems Center (Volpe Center) of the United States Department of Transportation has developed a modeling system to assist the National Highway Traffic Safety Administration in the evaluation of potential new Corporate Average Fuel Economy (CAFE) standards. Given 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.

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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 in the evaluation of potential new Corporate Average Fuel Economy (CAFE) standards. Given 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, relative to a given baseline scenario, 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 Model as of July 14, 2016; specifies the content, structure, and meaning of inputs and outputs; and provides instructions for the installation and use of the modeling system.

The authors acknowledge the technical contributions of present and former Volpe Center and NHTSA staff who have been involved in guiding recent changes to the modeling system, including Dan Bogard, Walter Gazda, Ryan Harrington, Ken Katz, Gregory Powell, Jim Tamm, Lixin Zhao, and Stephen Zoepf. The authors further acknowledge former DOT staff who participated in the development of earlier versions of the modeling system, including Gregory Ayres, Phil Gorney, Kristina Lopez-Bernal, José Mantilla, Joe Mergel, Arthur Rypinski, and Kenneth William.

The authors further acknowledge the technical contributions of individuals who have reviewed detailed results of the model (and/or earlier versions of the model) and/or provided specific suggestions regarding the model's design. Among these individuals are Steve Plotkin and Michael Wang of the Department of Energy's Argonne National Laboratory, Jeff Alson, William Charmley, Ben Ellies, David Haugen, Ari Kahan, Richard Rykowski, and Todd Sherwood of the U.S. Environmental Protection Agency (EPA), Gary Rogers of FEV Engine Technology, Inc., David Boggs, Anrico Casadei, Scott Ellsworth, and Sandy Stojkovski of Ricardo, Inc., Jamie Hulan of Transport Canada, and Jonathan Rubin of the University of Maine.

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Abbreviations

a..................................vehicle vintage
ADSL..........................advanced diesel engine
AERO.........................aerodynamic improvements technology
AMT...........................automated manual (i.e., clutch) transmission
ANL...........................Argonne National Laboratory
AT..............................automatic transmission
BEV200......................200-mile electric vehicle
BISG...........................belt mounted integrated starter/generator
BTU............................British thermal unit
C.................................regulatory class
CAFE..........................Corporate Average Fuel Economy
CH_4............................methane
CISG...........................crank mounted integrated starter/generator
CNG...........................compressed natural gas
CO.............................carbon monoxide
CO_2............................carbon dioxide
$COST_{eff}$.......................effective cost
$CREDIT_C$....................CAFE credits earned in regulatory class *C*
$CREDITIN_C$................CAFE credits transferred into a regulatory class *C*
$CREDITOUT_C$...........CAFE credits transferred out of a regulatory class *C*
CVT...........................continuously variable transmission
CW.............................vehicle's curb weight
CY..............................calendar year
DEAC.........................cylinder deactivation
DCT...........................dual-clutch transmission
DOE...........................U.S. Department of Energy
DOHC........................double overhead camshaft engine
EISA...........................Energy Independence and Security Act of 2007
EPA............................U.S. Environmental Protection Agency
EPCA..........................Energy Policy and Conservation Act
EV..............................electric vehicle
$\Delta FINE$........................change in civil penalties owed
FC..............................fuel consumption improvement factor
FCV............................fuel cell vehicle
FE...............................fuel economy of a vehicle
FFV............................flexible-fuel vehicle
FINE..........................civil penalties owed
FS..............................percentage of miles driven by a vehicle on a specific fuel type
FT..............................fuel type a vehicle operates on
GAP............................gap between laboratory and on-road fuel economy
GCWR........................gross combined weight rating
GGE...........................gasoline gallon equivalents
GVWR........................gross vehicle weight rating
HCR............................high compression ratio engine

HCR2..........................advanced high compression ratio engine
HCRP.........................high compression ratio "plus" engine
i.................................vehicle index
k.................................vehicle cohort index
kWh............................kilowatt-hour
LUBEFR.....................improved low friction lubricants and engine friction reduction
MSRP.........................manufacturer suggested retail price
MR.............................mass reduction technology
MT.............................manual (*i.e.*, clutch) transmission
MY.............................model year
N_2O............................nitrous oxide
NO_x............................oxides of nitrogen
OHV...........................overhead valve engine
PHEV.........................plug-in hybrid/electric vehicle
PHEV30.....................30-mile plug-in hybrid/electric vehicle
PHEV50.....................50-mile plug-in hybrid/electric vehicle
PB..............................payback period
PM.............................particulate matter
$PRICE_{FT}$.....................price of fuel type *FT*
Quads.........................quadrillion British thermal units
r.................................discount rate
ROLL..........................low rolling resistance tires technology
scf..............................standard cubic foot
SHEVP2.....................P2 strong hybrid/electric
SHEVPS.....................power-split strong hybrid/electric
SO_x............................sulfur oxides
SOHC.........................single overhead camshaft engine
STD............................value of the CAFE standard
SURV..........................average survival rate of a vehicle
SUV............................sport utility vehicle
v.................................vehicle vintage
$\boldsymbol{V}_C$...............................vector of all vehicle models in regulatory class *C*
$VALUE_{fuel}$...................value of saved fuel
VMT...........................vehicle miles traveled
VOC...........................volatile organic compounds
VVL............................variable valve lift
VVT............................variable valve timing
ZEV............................zero emission vehicle

Chapter One 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, an agency within the U.S. Department of Transportation, 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.

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

Since 2002, the Volpe Center has made many changes to this modeling system. Some changes were made in response to comments submitted to NHTSA in connection with CAFE rulemakings, and in response to a formal peer review of the system. Some changes were made based on observations by NHTSA and Volpe Center technical staff. As NHTSA began evaluating attribute-based CAFE standards (*i.e.*, standards under which CAFE requirements depend on the mix of vehicles produced for U.S. sale), significant changes were made to enable evaluation of such standards. At the same time, the system was expanded to provide the ability to perform uncertainty analysis by randomly varying many inputs. Later, the system was further expanded to provide automated statistical calibration of attribute-based standards, through implementation of Monte Carlo techniques, as well as automated estimation of stringency levels that meet specified characteristics (such as maximizing estimated net benefits to society). In 2007, NHTSA and Volpe Center staff worked with technical staff of the U.S. Environmental Protection Agency (EPA) on major changes to the range of fuel-saving technologies accommodated by the model, as well as the logical pathways for applying such technologies. In 2008, NHTSA and Volpe Center staff collaborated on further revisions, particularly with respect to the representation of available fuel-saving technologies, support for the reexamination of which was provided by Ricardo, Inc. In support of the 2010 rulemaking, a multi-year technology application feature was introduced into the modeling system. In 2011, a feature to evaluate voluntary overcompliance has been added as well.

In 2014, the system was adapted and expanded to allow NHTSA and Volpe Center staff to perform analysis in support of the medium duty rulemaking. As such, a new regulatory class, covering class 2b and class 3 pickups and vans, was introduced into the modeling system. To better illustrate the behavior of the industry, a feature allowing technologies to be inherited between vehicle platforms, engines, and transmissions has been reintroduced into the modeling system as the primary mode of operation. In 2016, the modeling system was further refined to allow simultaneous analysis of light duty and medium duty fleets, accounting for potential interaction between shared platforms, engines, and transmissions. Additionally, in 2016, the modeling system has undergone a major overhaul to allow for integration of vehicle simulation results from Argonne National Laboratory’s Autonomie model.

Chapter Two System Design

Section 1 Overall Structure

The basic design of the CAFE Model developed by the Volpe Center is as follows: The system first estimates how manufacturers might respond to a given CAFE scenario, and from that the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. A CAFE scenario involves specification of the form, or shape, of the standards (*e.g.*, flat standards, linear or logistic attribute-based standards, scope of passenger car and truck 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, provided by the user, of the vehicle models offered for sale during the simulation period. The compliance simulation then attempts to bring each manufacturer into compliance with CAFE standards defined in an input file developed by the user; for example, CAFE standards that increase in stringency by 4 percent per year for 5 consecutive years, and so forth. 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 civil penalties becomes more cost-effective than increasing vehicle fuel economy. The user may disable the civil penalty paying option for manufacturers expected to be unwilling to pay them, thus effectively "forcing" the manufacturer to add additional technology even once it might otherwise be preferable to pay penalties (considering the cost to add further technology as compared to the estimated value of the resultant saved fuel). At this stage, the system assigns an incurred technology cost and updated fuel economy to each vehicle model, as well as any civil penalties incurred by each manufacturer.

This point marks the system's transition between compliance simulation and effects calculations. At the conclusion of the compliance simulation for a given model year, the system contains a new fleet of vehicles with new prices, fuel types (*e.g.*, diesel, electricity), 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 and regulatory or vehicle class for the energy, carbon dioxide, criteria pollutant, and fatalities calculations. The system may be expanded in the future to represent CAFE-induced market responses (*i.e.*, mix shifting), in which case such calculations would group vehicles by market segment. Therefore, this system uses model-by-model categorization and accounting when calculating most effects, and aggregates results only as required for efficient reporting.

Section 2 CAFE Compliance Simulation

S2.1 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 Section A.4 of Appendix A. Each scenario describes an overall CAFE program in terms of the program's coverage, applicability of multi-fuel vehicles, the structure and stringency of the standards applicable to passenger cars, lights trucks, and class 2b and 3 trucks, as well as other miscellaneous settings that may have an impact on compliance. The system is normally used to examine and compare at least two scenarios. The first scenario is identified as the baseline scenario, usually defined as the world in the absence of new CAFE standards (which itself can be considered in a variety of ways), 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, the assumed preference of each manufacturer to pay civil penalties rather than complying with the program, and the degree of voluntary overcompliance allowed by the system. 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, platform, engine, and transmission in the fleet. The third and final step involves the repeated application of technologies to specific vehicle models, platforms, 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 to prefer to pay civil penalties for noncompliance, this step terminates when it would be less expensive to pay such penalties than to continue applying technology. Furthermore, if the system has been configured to evaluate voluntary overcompliance, this step would not terminate until all cost-effective solutions, for all manufacturers, were applied, beyond what is necessary to meet the CAFE standard.

S2.1.1 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 Section A.1 of Appendix A. The set of worksheets uses identification codes to link vehicle models to appropriate engines and transmissions. 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 realistically "carry over" technologies between model years.

Vehicle Models Worksheet

Veh ID	Model	FE	Sales		MSRP		Engine Code	Transmission Code
			MY11	MY12	MY11	MY12		
1	Veh1	20.95	11,516	10,963	27,500	28,875	1	2
2	Veh2	21.78	93,383	97,767	23,000	24,150	1	3
3	Veh3	18.33	46,880	49,367	31,250	32,813	2	4
4	Veh4	22.02	65,054	68,505	24,250	25,463	3	3
5	Veh5	18.51	21,843	25,838	31,500	33,075	4	4

Engine Worksheet

Eng ID	Name	Fuel	Cyl	Displacement	Valves per Cylinder
1	Eng1	G	6	3.5	2
2	Eng2	G	8	4	2
3	Eng3	G	6	3.5	4
4	Eng4	G	8	4	4

Transmission Worksheet

Trn ID	Name	Type	Gears	Control
1	M5	C	5	M
2	A4	T	4	A
3	A5	T	5	A
4	A6	T	6	A

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

S2.2 Vehicle Technology Application Within the CAFE Model

Vehicle technologies provide a set of possible improvements available for the vehicle fleet within the modeling system. The input assumptions for vehicle technologies, referred to below simply as "technologies", are defined by the user in the technology input file for the model. As part of the technology definition, the input file includes: additional cost associated with application of the technology, an improvement factor (in terms of percent reduction of fuel consumption), initial year that the technology may be considered for application, whether it is applicable to a given class of vehicle, as well as other miscellaneous assumptions outlining additional technology characteristics. Section A.2 of Appendix A describes all technology attributes in greater detail.

Internally, the system also assigns intrinsic properties for each technology defining the application schedule (further restricting when a technology may be considered for application) and the application level (controlling the scope of a technology's applicability). The application schedule determines whether a technology may be applied during a vehicle's redesign year only, during a vehicle's refresh or redesign years, or if the technology is defined as part of the baseline input fleet and is not available for application during modeling. The application level indicates whether the technology is vehicle-level, in which case it may be applied directly to individual vehicles, or if the technology is platform, engine, or transmission-level, in which case it will be applied to all vehicles that share a common platform, engine, or transmission.

The following two tables outline all technologies available within the modeling system, along with their application levels and schedules:

Table 1. CAFE Model Technologies (1)

Technology	Application Level	Application Schedule	Description
SOHC	Engine	Baseline Only	Single Overhead Camshaft Engine
DOHC	Engine	Baseline Only	Double Overhead Camshaft Engine
OHV	Engine	Baseline Only	Overhead Valve Engine
TEFRI	Engine	Redesign Only	Engine Friction Reduction Improvements (time-based)
LUBEFR1	Engine	Refresh/Redesign	Improved Low Friction Lubricants and Engine Friction Reduction
LUBEFR2	Engine	Redesign Only	LUBEFR2, Level 2
LUBEFR3	Engine	Redesign Only	LUBEFR2, Level 3
VVT	Engine	Refresh/Redesign	Variable Valve Timing
VVL	Engine	Redesign Only	Variable Valve Lift
SGDI	Engine	Redesign Only	Stoichiometric Gasoline Direct Injection
DEAC	Engine	Redesign Only	Cylinder Deactivation
HCR	Engine	Redesign Only	High Compression Ratio Engine
HCRP	Engine	Redesign Only	High Compression Ratio "Plus" Engine
TURBO1	Engine	Redesign Only	Turbocharging and Downsizing, Level 1 (18 bar)
SEGR	Engine	Redesign Only	Stoichiometric Exhaust Gas Recirculation
DWSP	Engine	Redesign Only	Engine Downspeeding
TURBO2	Engine	Redesign Only	Turbocharging and Downsizing, Level 2 (24 bar)
CEGR1	Engine	Redesign Only	Cooled Exhaust Gas Recirculation, Level 1 (24 bar)
CEGR1P	Engine	Redesign Only	Cooled Exhaust Gas Recirculation, Level 1 "Plus" (24 bar)
CEGR2	Engine	Redesign Only	Cooled Exhaust Gas Recirculation, Level 2 (27 bar)
HCR2	Engine	Redesign Only	Advanced High Compression Ratio Engine
CNG	Engine	Baseline Only	Compressed Natural Gas Engine
ADSL	Engine	Redesign Only	Advanced Diesel
TURBODSL	Engine	Redesign Only	Improved Diesel Turbocharger
DWSPDSL	Engine	Redesign Only	Diesel Engine Downspeeding with Increased Boost
EFRDSL	Engine	Redesign Only	Diesel Engine Friction Reduction
CLCDSL	Engine	Redesign Only	Closed Loop Combustion Control
LPEGRDSL	Engine	Redesign Only	Low Pressure Exhaust Gas Recirculation
DSIZEDSL	Engine	Redesign Only	Diesel Engine Downsizing

In Table 1 above, note that SOHC, DOHC, and OHV engine technologies are defined as baseline-only. These technologies are used to inform the modeling system of the input engine's configuration in order to correctly account for synergy adjustments of fuel consumption improvement factors (technology synergies are further discussed below). Note that CNG engine technology is defined as baseline-only as well. While it may be present in the input fleet, this technology is not directly applicable by the model.

Table 2. CAFE Model Technologies (2)

Technology	Application Level	Application Schedule	Description
MT5	Transmission	Baseline Only	5-Speed Manual Transmission
MT6	Transmission	Redesign Only	6-Speed Manual Transmission
MT7	Transmission	Redesign Only	7-Speed Manual Transmission
TATI	Transmission	Refresh/Redesign	Automatic Transmission Improvements (time-based)
AT5	Transmission	Baseline Only	5-Speed Automatic Transmission
AT6	Transmission	Redesign Only	6-Speed Automatic Transmission
AT6P	Transmission	Redesign Only	6-Speed "Plus" Automatic Transmission
AT8	Transmission	Redesign Only	8-Speed Automatic Transmission
AT8P	Transmission	Redesign Only	8-Speed "Plus" Automatic Transmission
DCT6	Transmission	Redesign Only	6-Speed Dual Clutch Transmission
DCT8	Transmission	Redesign Only	8-Speed Dual Clutch Transmission
CVT	Transmission	Redesign Only	Continuously Variable Transmission
EPS	Vehicle	Refresh/Redesign	Electric Power Steering
IACC1	Vehicle	Refresh/Redesign	Improved Accessories - Level 1
IACC2	Vehicle	Refresh/Redesign	Improved Accessories - Level 2 (w/ Alternator Regen and 70% Efficient Alternator)
SS12V	Vehicle	Refresh/Redesign	12V Micro-Hybrid (Stop-Start)
BISG	Vehicle	Redesign Only	Belt Mounted Integrated Starter/Generator
CISG	Vehicle	Redesign Only	Crank Mounted Integrated Starter/Generator
SHEVP2	Vehicle	Redesign Only	P2 Strong Hybrid/Electric Vehicle
SHEVPS	Vehicle	Redesign Only	Power Split Strong Hybrid/Electric Vehicle
PHEV30	Vehicle	Redesign Only	30-mile Plug-In Hybrid/Electric Vehicle
PHEV50	Vehicle	Redesign Only	50-mile Plug-In Hybrid/Electric Vehicle
BEV200	Vehicle	Redesign Only	200-mile Electric Vehicle
FCV	Vehicle	Redesign Only	Fuel Cell Vehicle
LDB	Vehicle	Refresh/Redesign	Low Drag Brakes
SAX	Vehicle	Refresh/Redesign	Secondary Axle Disconnect
ROLL10	Vehicle	Refresh/Redesign	Low Rolling Resistance Tires, Level 1 (10% Reduction)
ROLL20	Vehicle	Refresh/Redesign	Low Rolling Resistance Tires, Level 2 (20% Reduction)
MR1	Platform	Refresh/Redesign	Mass Reduction, Level 1 (5% Reduction in Glider Weight)
MR2	Platform	Redesign Only	Mass Reduction, Level 2 (7.5% Reduction in Glider Weight)
MR3	Platform	Redesign Only	Mass Reduction, Level 3 (10% Reduction in Glider Weight)
MR4	Platform	Redesign Only	Mass Reduction, Level 4 (15% Reduction in Glider Weight)
MR5	Platform	Redesign Only	Mass Reduction, Level 5 (20% Reduction in Glider Weight)
AERO10	Platform	Refresh/Redesign	Aero Drag Reduction, Level 1 (10% Reduction)
AERO20	Platform	Redesign Only	Aero Drag Reduction, Level 2 (20% Reduction)

In Table 2 above, note that MT5 and AT5 transmission technologies are both defined as baseline-only. While they may be present in the input fleet, these technologies are not directly applicable by the model.

The modeling system defines several technology classes and pathways for logically grouping all available technologies for application on a vehicle. Technology classes provide costs and improvement factors shared by all vehicles with similar body styles, curb weights, footprints, and engine types, while technology pathways establish a logical progression of technologies on a vehicle.

S2.2.1 Technology Classes

The modeling system defines two types of technology classes: the vehicle technology classes and the engine technology classes. The system utilizes vehicle technology classes as a means for specifying common technology input assumptions for vehicles that share similar characteristics. Predominantly, these classes signify the degree of applicability of each of the available technologies to a specific class of vehicles, as well as determine the base improvement factors attributed to those technologies. Furthermore, for each technology, the vehicle technology classes also define the amount by which the vehicle's weight may decrease (resulting from application of mass reducing technology), and the additional cost associated with application of non-engine-level technologies.

The model supports seven vehicle technology classes as shown in Table 3:

Table 3. Vehicle Technology Classes

Class	Description
SmallCar	Small passenger cars
MedCar	Medium to large passenger cars
SmallSUV	Small sport utility vehicles and station wagons
MedSUV	Medium to large sport utility vehicles, minivans, and passenger vans
Pickup	Light duty pickups and other vehicles with ladder frame construction
Truck 2b/3	Class 2b and class 3 pickups
Van 2b/3	Class 2b and class 3 cargo vans

Since the costs attributed to application of engine-level technologies vary based upon the engine configuration (such as number of engine cylinders or banks), the model defines separate engine classes for specifying input costs for these technologies. The modeling system provides sixteen engine technology classes as shown in Table 4:

Table 4. Engine Technology Classes

Class	Description
2C1B	SOHC/DOHC engine with 2 cylinders and 1 bank
3C1B	SOHC/DOHC engine with 3 cylinders and 1 bank
4C1B	SOHC/DOHC engine with 4 cylinders and 1 bank
4C2B	SOHC/DOHC engine with 4 cylinders and 2 banks
5C1B	SOHC/DOHC engine with 5 cylinders and 1 bank
6C1B	SOHC/DOHC engine with 6 cylinders and 1 bank
6C1B_ohv	OHV engine with 6 cylinders and 1 bank
6C2B	SOHC/DOHC engine with 6 cylinders and 2 banks
6C2B_ohv	OHV engine with 6 cylinders and 2 banks
8C2B	SOHC/DOHC engine with 8 cylinders and 2 banks
8C2B_ohv	OHV engine with 8 cylinders and 2 banks
10C2B	SOHC/DOHC engine with 10 cylinders and 2 banks
10C2B_ohv	OHV engine with 10 cylinders and 2 banks
12C2B	SOHC/DOHC engine with 12 cylinders and 2 banks
12C4B	SOHC/DOHC engine with 12 cylinders and 4 banks
16C4B	SOHC/DOHC engine with 16 cylinders and 4 banks

Once the inputs for technology classes are defined, the user would assign each vehicle in the input fleet to use an appropriate vehicle and engine technology classes. The model would then use the technology class assignments to obtain the appropriate applicability, improvement factor, and cost for each technology as appropriate for an individual vehicle.

S2.2.2 Technology Pathways

The modeling system defines technology pathways for grouping and establishing a logical progression of technologies on a vehicle. Each pathway (or path) is evaluated independently and in parallel, with technologies on these paths being iterated in sequential order. As the model traverses each path, the costs and improvement factors are accumulated on an incremental basis with relation to the preceding technology. The system stops examining a given path once a combination of one or more technologies results in a "best" technology solution for that path.[1] After evaluating all paths, the model selects a most cost-effective solution among all pathways. This "parallel path" approach allows the modeling system to progress thorough technologies in any given pathway without being unnecessarily prevented from considering technologies in other paths.

The modeling system incorporates thirteen technology pathways for evaluation as shown in Table 5. Similar to individual technologies, each path carries an intrinsic application level that denotes the scope of applicability of all technologies present within that path, and whether the pathway is evaluated on one vehicle at a time, or on a collection of vehicles that share a common platform, engine, or transmission.

Table 5. Technology Pathways

Technology Pathway	Application Level
Basic Engine Path	Engine
Turbo Engine Path	Engine
Advanced Engine Path	Engine
Diesel Engine Path	Engine
Manual Transmission Path	Transmission
Automatic Transmission Path	Transmission
Electrification Path	Vehicle
Hybrid/Electric Path	Vehicle
Advanced Hybrid/Electric Path	Vehicle
Dynamic Load Reduction Path	Vehicle
Low Rolling Resistance Tires Path	Vehicle
Mass Reduction Path	Platform
Aerodynamic Improvements Path	Platform

The technologies that comprise the four Engine-Level paths available within the model are presented in Figure 2 below. Note that the baseline-level technologies (SOHC, DOHC, OHV,

[1] 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 pathways in a manner that minimizes effective costs, which include (a) vehicle price increases associated with added technologies, (b) for manufacturers that prefer to pay civil penalties, reductions in civil penalties owed for noncompliance with CAFE standards, (c) the value vehicle purchasers are estimated to place on fuel economy, and (d) any changes in consumer valuation attributed to the added technologies.

and CNG) are grayed out. As mentioned earlier, these technologies are used to inform the modeling system of the input engine's configuration, and are not otherwise applicable during the analysis.

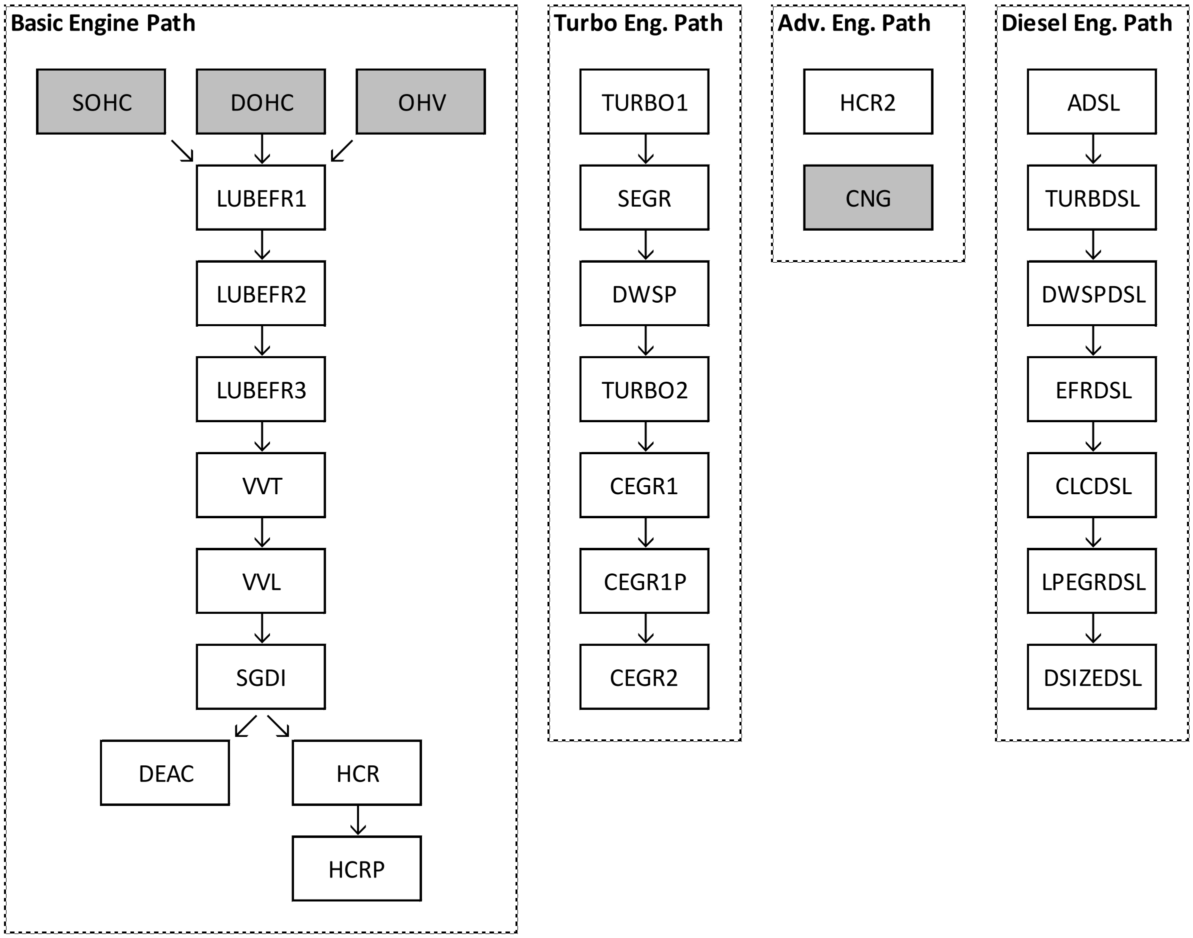

Figure 2. Engine-Level Paths

For all pathways, the technologies are evaluated and applied to a vehicle in sequential order, as shown, from top to bottom. In some cases, however, if a technology is deemed ineffective, the system will bypass it and skip ahead to the next available technology. If the modeling system applies a technology that resides later in the pathway, it will "backfill" anything that was previously skipped in order to fully account for costs and improvement factors, each of which are specified on an incremental basis. For any technology that is already present on a vehicle (either from the input fleet or previously applied by the model), the system skips over those technologies as well and proceeds to the next. These skipped technologies, however, will not be applied again during backfill.

The Basic Engine path begins with SOHC, DOHC, and OHV technologies defining the initial configuration of the vehicle's engine. Since these technologies are not available during modeling, the system evaluates this pathway starting with LUBEFR1 technology. Toward the end of the path, the model encounters a choice between DEAC and HCR technologies. Whenever a technology pathways forks into two or more branch points, all of the branches are treated as mutually exclusive. The system evaluates all technologies forming the branch, and selects the most costs-effective for application, while disabling the remaining. In the case of the Basic Engine path, that means if a vehicle continues with application of the DEAC technology, the HCR and HCRP technologies will be disabled. Likewise, if the vehicle applies the HCR technology, the HCRP technology will still be available for evaluation, while the DEAC technology will be disabled.

The technologies exposed by the Advanced Engine path (HCR2 and CNG) are not incremental over each other and do not follow a traditional progression logic present on other paths. Consequently, these technologies are treated as mutually exclusive within the model. Since CNG is a baseline-level technology, the only remaining choice for application within the Advanced Engine path is HCR2.

The technologies that make up the two Transmission-Level paths defined by the modeling system are shown in Figure 3 below. The baseline-level technology (MT5 and AT5) are grayed and are only used to signify the initial configuration of the vehicle's transmission. For simplicity, all manual transmissions with five forward gears or fewer should be assigned the MT5 technology in the input fleet. Similarly, all automatic transmissions with five forward gears or fewer should be assigned the AT5 technology.

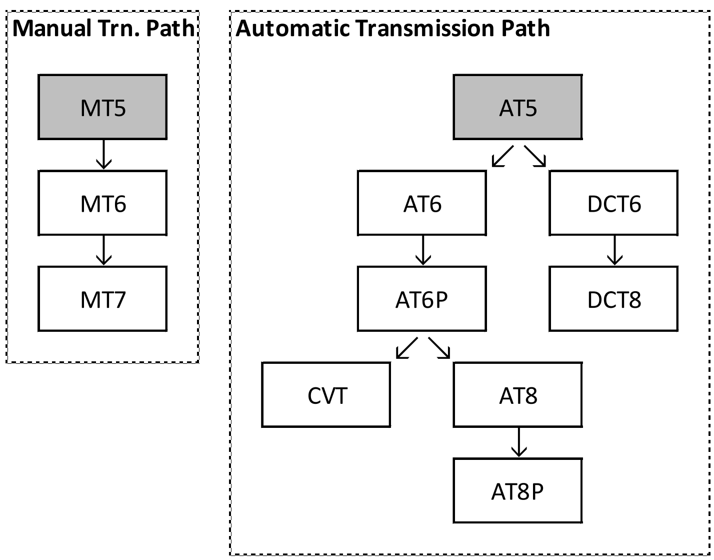

Figure 3. Transmission-Level Paths

Given the definition of incremental costs and fuel consumption improvement factors utilized during the analysis, the system assumes that all manual transmissions with seven or more gears are mapped to the MT7 technology. Moreover, the AT8 technology should map to all automatic transmissions with seven or more forward gears, DCT6 technology should map to all dual-clutch (DCT) or auto-manual (AMT) transmissions with five or six forward gears, and DCT8 technology should map to all DCT's or AMT's with seven or more forward gears. These transmission technology utilization assignments, however, are defined within the input fleet, and are not strictly enforced by the modeling system.

As mentioned earlier, the branch points, as shown in the Automatic Transmission path, are mutually exclusive. For example, if a vehicle transitions to the DCT branch, the CVT and all AT*n* technologies will become unavailable.

The technologies that compose the two Platform-Level paths provided by the model are displayed in Figure 4 below.

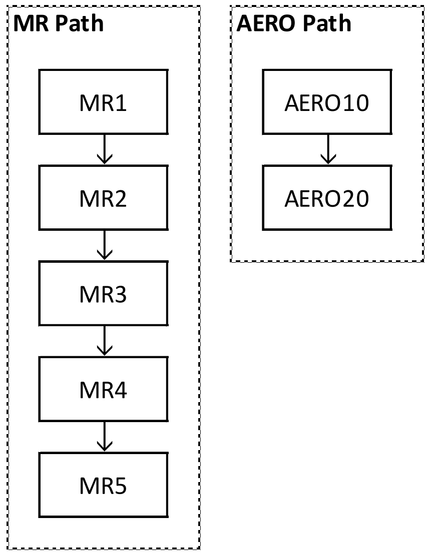

Figure 4. Platform-Level Paths

The technologies that constitute the five Vehicle-Level paths defined by the system are outlined in Figure 5 below.

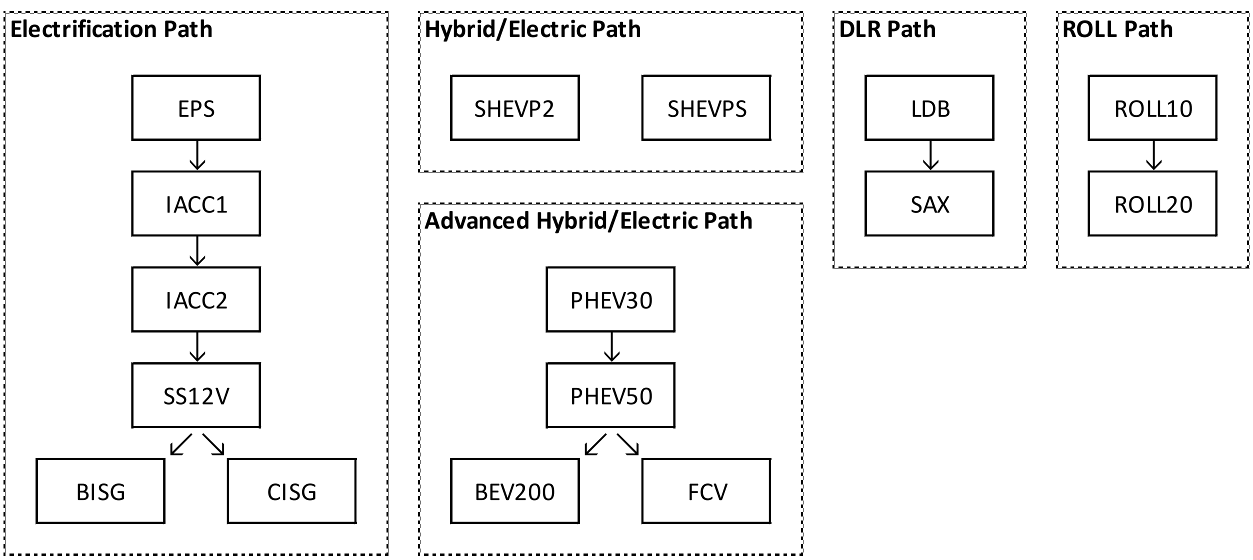

Figure 5. Vehicle-Level Paths

The technologies on the Hybrid/Electric path (SHEVP2 and SHEVPS) are defined as stand-alone and mutually exclusive. These technologies are not incremental over each other and do not follow a traditional progression logic present on other paths.

Even though the model evaluates each technology path independently, some of the pathways are interconnected to allow for additional logical progression and incremental accounting of technologies. For example, the SHEVPS (power-split strong hybrid/electric) technology on the Hybrid/Electric path is defined as incremental over the DEAC (cylinder deactivation) technology on the Basic Engine path, the AT5 (5-speed automatic) technology on the Automatic Transmission path, and the CISG (crank mounted integrated starter/generator) technology on the Electrification path. For that reason, whenever the system evaluates the SHEVPS technology for application on a vehicle, it ensures that, at a minimum, all the aforementioned technologies (as well as their predecessors) have already been applied on that vehicle.

Of the thirteen technology pathways present in the model, all Engine paths, the Automatic Transmission path, the Electrification path, and both Hybrid/Electric paths are logically linked for incremental technology progression. This relationship between pathways is illustrated in Figure 6 below.

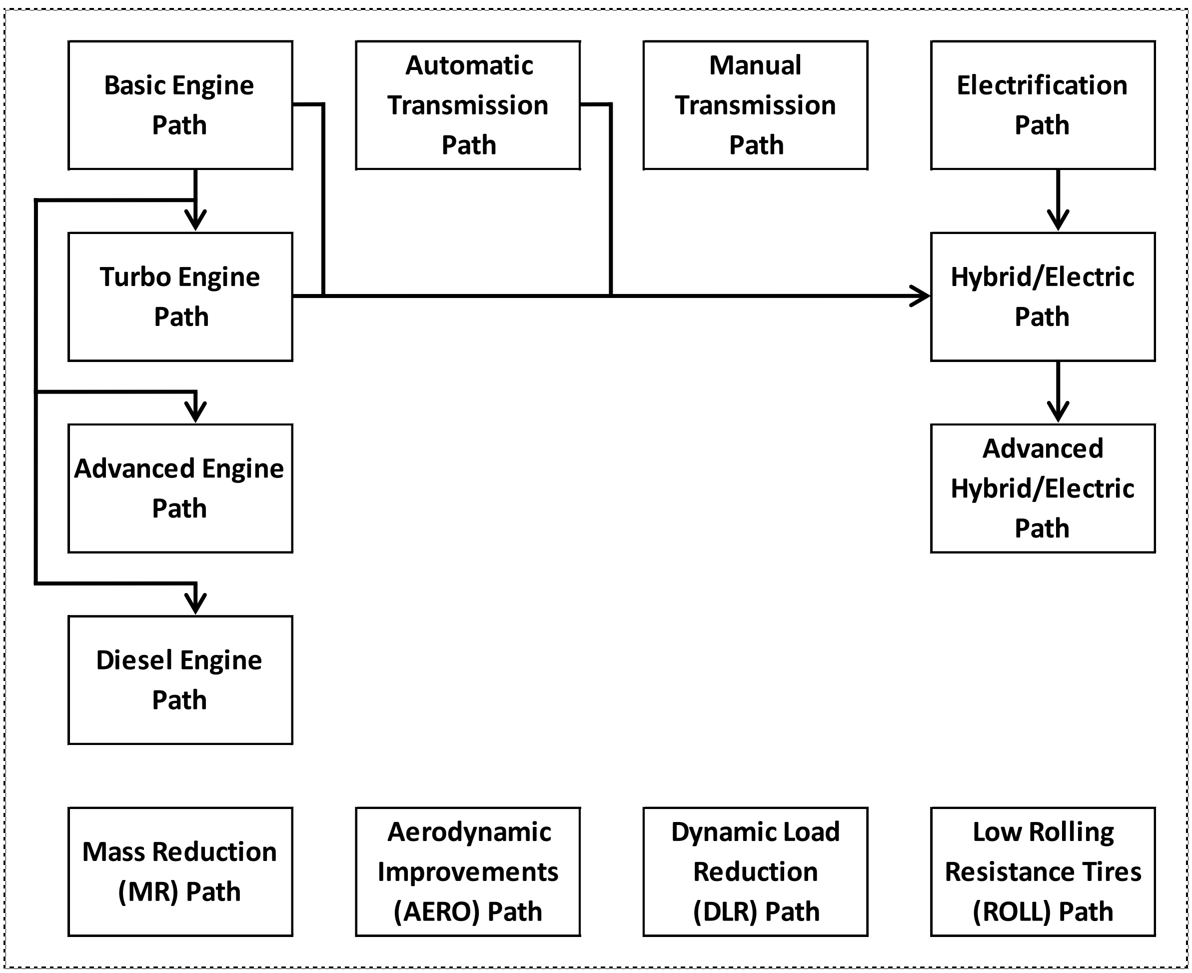

Figure 6. Technology Pathways Diagram

Some of the technology pathways, as defined in the CAFE model and shown in the diagram above, may not be compatible with a vehicle given its state at the time of evaluation. For example, a vehicle with a 6-speed automatic transmission will not be able to get improvements from a Manual Transmission path. For this reason, the system implements logic to explicitly disable certain paths whenever a constraining technology from another path is applied on a vehicle. On occasion, not all of the technologies present within a pathway may produce compatibility constraints with another path. In such a case, the system will selectively disable a conflicting pathway (or part of the pathway) as required by the incompatible technology. The precise logic for conflicting pathways defined within the model is shown in the table below:

Table 6. Technology Pathway Compatibility Logic

Technology Pathway	Conflicting Pathways Disabled in the Model
Turbo Engine Path	Advanced Engine Path Diesel Engine Path
Advanced Engine Path	Turbo Engine Path Diesel Engine Path Both Hybrid/Electric Paths (except if HCR2-only is used)
Diesel Engine Path	Turbo Engine Path Advanced Engine Path Both Hybrid/Electric Paths
Manual Transmission Path	Automatic Transmission Path Electrification Path (only micro-/mild-HEV technologies) Both Hybrid/Electric Paths
Automatic Transmission Path	Manual Transmission Path
Hybrid/Electric Paths (including adv. H/E)	Turbo Engine Path (except if SHEVP2-only is used) Advanced Engine Path (except if SHEVP2-only is used) Diesel Engine Path

In addition to the logic described in Table 6, for any interlinked technology pathways shown in Figure 6 above, the system also disables all preceding technology paths whenever a vehicle transitions to a succeeding pathway. For example, if the model applies SHEVPS technology on a vehicle, the system disables the Turbo, Advanced, and Diesel Engine paths (as defined above), as well as the Basic Engine, the Automatic Transmission, and the Electrification paths (all of which precede the Hybrid/Electric path).[2]

S2.2.3 Technology Applicability

The modeling system determines the applicability of each technology on a vehicle, engine, transmission, or platform using the combination of technology input assumptions and the technology utilization settings defined in the input fleet (as specified in the market data input file).[3]

For each vehicle technology class (discusses above), the technology input assumptions provide the *Applicable*, *Year Available*, and *Year Retired* fields that control the scope of applicability of each technology. If the *Applicable* field is set to **FALSE** for a specific technology, that technology will not be available for evaluation. Conversely, if this field is set to **TRUE**, the

[2] The only notable exception to this rule occurs whenever SHEVP2 technology is applied on a vehicle. This technology may be present in conjunction with any engine-level technology, and as such, the Basic Engine path is not disabled upon application of SHEVP2 technology, even though this pathway precedes the Hybrid/Electric path.

[3] The technology utilization section is described in Sections A.1.2, A.1.3, and A.1.4 of Appendix A.

technology will be available for application. Furthermore, the *Year Available* and *Year Retired* fields determine the minimum and maximum model years during which the technology may be considered by the modeling system. Additionally, technology phase-in caps may limit the availability of technologies if a particular penetration rate is reached for a vehicle's manufacturer in a model year being evaluated.

In the market data input file, the worksheets describing each vehicle model, engine, and transmission selected for simulation provide the *Technology Information* sections that are used to define the initial technology utilization state of the input fleet. Each of the CAFE model technologies listed in Table 1 and Table 2 above are referenced on these worksheets as appropriate, based on the application-level of the technology. The user determines which technologies are initially present in the input fleet, given the characteristics of each vehicle, engine, and transmission. Since the modeling system relies heavily on the *Technology Information* settings, these sections must accurately and completely represent the initial state of each vehicle, platform, engine, and transmission in order to avoid potential modeling errors.

Lastly, the logical restrictions imposed by the technology pathways described above further restrict the applicability of technologies should any compatibility issues arise during modeling.

S2.2.4 Technology Evaluation and Inheriting

Once the system determines the applicability of all technologies, it may begin evaluating them for application on a vehicle. As stated before, the system examines each pathway sequentially, bypassing and backfilling technologies whenever necessary. The model considers and applies redesign-based technologies (as defined in Table 1 and Table 2 above) whenever a vehicle is at a redesign, while refresh-based technologies may be considered during a vehicle's refresh or redesign years.

When the system evaluates platform, engine, or transmission-level technologies, since the technology being analyzed directly modifies a shared vehicle component[4], the resultant improvements must be considered on all vehicles that utilize a common platform, engine, or transmission simultaneously. During modeling, the system elects a "leader" vehicle, with all technology improvements being realized on that vehicle first, and afterwards, propagated down to the remainder of the vehicles (known as the "followers") that share the leader's platform, engine, or transmission. As such, new technologies are initially evaluated and applied to a leader vehicle during its refresh or redesign year (as appropriate for a specific technology). Any follower vehicles that share the same redesign and/or refresh schedule as the leader apply these technology improvements during the same model year. The rest of the followers inherit refresh-based technologies from a leader vehicle during a follower's respective refresh or redesign year, while redesign-based technologies are inherited on a follower vehicle during its redesign year only.

[4] For the purposes of CAFE modeling, a vehicle component is defined as any major vehicle block that maintains its own production line and is utilized on multiple vehicles at a time. Vehicle platforms, engines, and transmissions are all considered to be vehicle components from the model's perspective.

The system dynamically assigns a leader vehicle for each platform, engine, and transmission during analysis, based on the following criteria:

1) For vehicle platforms only, the system first determines which of the shared vehicles have the highest degree of platform-level technology utilization,[5]
2) The system filters out (ignores) vehicles that have production volumes in only a few analysis years,
3) From the filtered list of vehicles, the system selects a vehicle model with the lowest production volumes (averaged across all analysis years) as the leader,
4) If multiple vehicles are selected (that is, they all have the same average production volumes), the vehicle with the highest MSRP is then chosen as the leader.

Note that, since platforms, engines, and transmissions do not always encompass the same set of vehicles, a vehicle chosen as the leader of an engine may not necessarily be selected as a leader of a platform or transmission.

Since vehicle-level technologies affect only one vehicle at a time, all technology improvements are applied immediately to just the one vehicle model during its refresh or redesign year.

S2.2.5 Technology Fuel Consumption Improvement Factors

The technology input assumptions define the base fuel consumption improvement factor *FC* for each modeled technology. The *FC* value is defined on a gallons-per-mile basis and represents a percent reduction in vehicle's fuel consumption value. The formula to find the resulting increase in fuel economy (miles-per-gallon) of a vehicle with fuel consumption reduction factors from one or more technologies is defined as:

$$FE_{new} = FE_{orig} \times \frac{1}{(1 - FC_0)} \times \frac{1}{(1 - FC_1)} \cdots \times \frac{1}{(1 - FC_n)} \quad \textbf{(1)}$$

Where:

FE_{orig} : the original fuel economy for the vehicle,
$FC_{0,1,\ldots n}$: the fuel consumption improvement factors attributed to the *0-th* to *n-th* technologies, and
FE_{new} : the resulting fuel economy for the same vehicle.

For approximately two-thirds of the technologies represented within the modeling system, the fuel consumption improvement factors were derived from a database containing detailed vehicle simulation results, analyzed at Argonne National Laboratory using the Autonomie model. In order to incorporate the results of the Argonne database, while still preserving the basic structure

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[5] Unlike engines and transmissions, the vehicle platforms are not discretely defined in the market data input file. Instead, technology utilization of platform-level technologies is attributed to individual vehicles. Therefore, on occasion, vehicles that share a common platform may begin the analysis with varying degrees of platform-level technologies. For this reason, the system begins the leader selection process by first filtering for vehicles with the highest utilization of these technologies.

of the CAFE model's technology subsystem, it was necessary to translate the points in the database into corresponding locations defined by the technology pathways, described in Section S2.2.2 above. By recognizing that most of the pathways are unrelated, and are only logically linked to allow for incremental technology progression, it is possible to rearrange the paths into a smaller number of groups and branches by technology type. To achieve this level of linearity, we define following technology groups: engine cam configuration (CONFIG), engine technologies (ENG), transmission technologies (TRANS), electrification and hybridization (ELEC), mass reduction levels (MR), aerodynamic improvements (AERO), and rolling resistance (ROLL).[6] The combination of technology levels along each of these paths define a unique technology combination that corresponds to a single point in the database for each technology class. These technology state definitions are more important for defining synergies than for determining incremental effectiveness, but the paths are incorporated into both.

As an example, a technology state vector describing a vehicle with a SOHC engine, variable valve timing (only), a 6-speed automatic transmission, a belt-integrated starter generator, mass reduction (level 1), aerodynamic improvements (level 2), and rolling resistance (level 1) would be specified as SOHC;VVT;AT6;BISG;MR1;AERO20;ROLL10. By assigning each technology state a vector such as the one in the example, the CAFE model can assign each vehicle in the analysis fleet an initial state that corresponds to a point in the database. From there, it is relatively simple to assign a percentage improvement to any new combination of technologies and apply that percentage improvement to the fuel consumption of a vehicle in the analysis fleet.

Once a vehicle is assigned a technology state (one of the tens of thousands of unique 7-tuples, defined in the technology input file as CONFIG;ENG;TRANS;ELEC;MR;AERO;ROLL), adding a new technology to the vehicle simply represents progress from one technology state to another. Then the formula to find the increase in vehicle's fuel economy shown in Equation (1) becomes:

$$FE_{new} = FE_{orig} \times \frac{1}{(1 - FC_0)} \times \frac{1}{(1 - FC_1)} \cdots \times \frac{1}{(1 - FC_n)} \times \frac{S_{orig}}{S_{new}} \qquad \textbf{(2)}$$

Where:

FE_{orig} : the original fuel economy for the vehicle,
$FC_{0,1,\ldots n}$: the fuel consumption improvement factors attributed to the *0-th* to *n-th* technologies,
S_{oirg} : the synergy factor associated with the technology state before application of any of the *0-th* to *n-th* technologies,
S_{new} : the synergy factor associated with the technology state after application of the *0-th* to *n-th* technologies, and
FE_{new} : the resulting fuel economy for the same vehicle.

[6] Since none of the technologies within the Dynamic Load Reduction path were simulated by Argonne, this pathway is not represented by the technology group combination.

The synergy factor is defined in a way that captures the incremental improvement of moving between points in the database, where each point is defined uniquely as a 7-tuple describing its cam configuration, highest engine technology, transmission, electrification type, mass reduction level, and level of aerodynamic or rolling resistance improvement.

For some technologies, the modeling system may convert a vehicle or a vehicle's engine from operating on one type of fuel to another. For example, application of Advanced Diesel (ADSL) technology converts a vehicle from gasoline operation to diesel operation. In such a case, the aforementioned Equations (1) and (2) still apply, however, in each case, the FE_{new} value is assigned to the vehicle's new fuel type, while the fuel economy on the original fuel is discarded.

Moreover, whenever the modeling system converts a vehicle model to a 30-mile Plug-In Hybrid/Electric Vehicle (PHEV30), that vehicle is assumed to operate simultaneously on gasoline and electricity fuel types. In this case, the *FC* and the *Secondary FC* fields, defined in the technology input file, are used to estimate the FE_{new} values on gasoline and electricity, respectively. In the case of electricity, the *Secondary FC* field is defined as an improvement over FE_{orig} on gasoline. For PHEVs, the *Secondary FS* field specifies the assumed amount of miles driven by the vehicle when operating on electricity. The vehicle's overall rated fuel economy is then defined as the average of the fuel economies on gasoline and electricity, weighted by the fuel shares.[7] As the system transitions to PHEV50, the same calculation applies, however, this time, *Secondary FC* field is defined as an improvement factor over FE_{orig} on electricity.

When the system further improves the vehicle, converting it from a PHEV50 to a 200-mile Electric Vehicle (BEV200), the gasoline fuel component is removed, while the electric-operated portion remains. In this case, the *FC* field represents an improvement factor over FE_{orig} on PHEV50's electricity component.

Lastly, for non-liquid fuel types, such as CNG, electricity, and hydrogen, the *FC* improvement and the resulting FE_{new} are assumed to be specified in gasoline gallon equivalents of energy use.

S2.2.6 Technology Cost Tables

The technology input assumptions provide a fully "learned-out" table of year-by-year technology costs, as specified by the *Cost Table* field. As mentioned earlier, the costs for engine-level technologies are specified for each engine technology class, while the costs for all other technologies are defined for each vehicle technology class.

For most of the technologies, the costs provided are used as is. However, for all technologies on the Mass Reduction path, the input costs are specified on per pound basis, where the base cost value is multiplied by the amount of pounds by which a vehicle's glider weight is reduced, in order to obtain the full cost of applying the technology. Additional effects of mass reduction technologies are discussed in Section S2.2.7 below.

[7] The overall fuel economy for PHEVs is the rated value achieved by the vehicle assuming on-road operation specified by the *Secondary FS* field. For compliance purposes, the vehicle's overall fuel economy is determined by the *Multi-Fuel* and the *PHEV Share* parameters defined in the scenarios input file. The scenarios input file is further discussed in Section A.4 of Appendix A.

The modeling system also incorporates cost adjustment factors to provide accounting corrections for technology costs. Since the Basic Engine path (see Figure 2 above) converges from SOHC, DOHC, and OHV technologies, and since the base input costs are defined for the DOHC path, the system necessitates the use of these adjustments in order to offset the costs of some basic engine technologies used on the SOHC and OHV engines. Given the new structure input file and logical representation of technologies within the current version of the model, at present, the cost adjustments for only a few engine technologies are required to be defined in the technologies input file.

Along with the base *Cost Table*, the input assumptions also define the *Maintenance Cost Table* and the *Repair Cost Table*. Both of these tables are specified for each model year and account for the learning effect, wherever applicable. The former identifies the changes in the amount buyers are expected to pay for maintaining a new vehicle[8], while the latter identifies the increases in non-warranty repair costs attributed to application of additional technology. Additionally, the input assumptions include the *Stranded Capital Table*, which associates a penalty cost for each technology that is replaced (or superseded) prior to fully amortizing the initial investment associated with that technology.

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

S2.2.7 Application of Mass Reduction Technology

When the modeling system evaluates application of mass reduction technology, the vehicle's new payload and towing capacity may be influenced as well by way of adjusting the gross vehicle weight rating (GVWR) and gross combined weight rating (GCWR) values. The degree by which GVWR and GCWR are affected is controlled in the scenarios input file through the *Payload Return* and *Towing Return* parameters. The calculation of new GVWR and GCWR are represented by the following formulas:

$$GVWR_{new} = \text{MIN}\begin{pmatrix} GVWR - PayloadReturn \times (CW - CW_{new}), \\ CW_{new} \times \left(\frac{GVWR}{CW}\right)_{MAX} \end{pmatrix} \quad \textbf{(3)}$$

$$GCWR_{new} = \text{MIN}\begin{pmatrix} GCWR - TowingReturn \times (GVWR - GVWR_{new}), \\ GVWR_{new} \times \left(\frac{GCWR}{GVWR}\right)_{MAX} \end{pmatrix} \quad \textbf{(4)}$$

Where:

CW	:	vehicle's curb weight prior to application of mass reduction technology,
CW_{new}	:	vehicle's curb weight following application of mass reduction technology,

[8] The maintenance costs may lead to increases in cost to consumers, such as for advanced diesel engines, or in cost saving to consumers, such as for electric vehicles. In the case of electric vehicles, the cost savings result from avoiding traditional vehicle maintenance such as engine oil changes.

$GVWR$	:	vehicle's GVWR prior to application of mass reduction technology,
$GVWR_{new}$	:	vehicle's GVWR following application of mass reduction technology,
$GCWR$	:	vehicle's GCWR prior to application of mass reduction technology,
$GCWR_{new}$	:	vehicle's GCWR following application of mass reduction technology,
$PayloadReturn$	:	the % of CW reduction returned to payload capacity,
$TowingReturn$	:	the % of GVWR reduction returned to towing capacity,
$\left(\frac{GVWR}{CW}\right)_{MAX}$	:	the limiting factor, defined for each input vehicle, preventing GVWR from increasing beyond levels observed among the majority of similar vehicles, and
$\left(\frac{GCWR}{GVWR}\right)_{MAX}$	:	the limiting factor, defined for each input vehicle, preventing GCWR from increasing beyond levels observed among the majority of similar vehicles.

Note that this adjustment is only relevant for class 2b and class 3 pickups and vans. In order to prevent the vehicles in these classes from crossing into the light duty category, and thus be treated as light duty vehicles for regulatory purposes, the $GVWR_{new}$ is further capped to prevent decreasing below 8501 lbs.

S2.3 Compliance Simulation Loop

Having determined the applicability of each technology to each vehicle model, platform, engine, and 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 next "best" technology available on each of the parallel technology paths mentioned above, and applying the best of these. The algorithm combines some of the pathways, evaluating them sequentially instead of in parallel, in order to ensure appropriate incremental progression of technologies. Figure 7 below gives an overview of the process.

The algorithm first finds the best next applicable technology in each of the technology pathways, then selects the best among these. If a manufacturer is assumed to be unwilling to pay CAFE civil penalties (or, equivalently, if the user has set the system to exclude the possibility of paying civil penalties as long as some technology can still be applied), then the algorithm applies the technology to the affected vehicles. Afterwards, the algorithm reevaluates the manufacturer's degree of noncompliance and continues application of technology. Once a manufacturer reaches compliance (*i.e.*, the manufacturer no longer pays CAFE civil penalties), the algorithm proceeds to apply any additional technology determined to be cost-effective (as defined below). Conversely, if a manufacturer is assumed to prefer to pay CAFE civil penalties, the algorithm only applies technology if it is cost-effective to do so. The algorithm stops applying additional technology to this manufacturer's products once no more cost-effective solutions are encountered.

This process is repeated for each manufacturer present in the input fleet. It is then repeated again for each modeling year. Once all modeling years have been processed, the compliance simulation algorithm concludes.

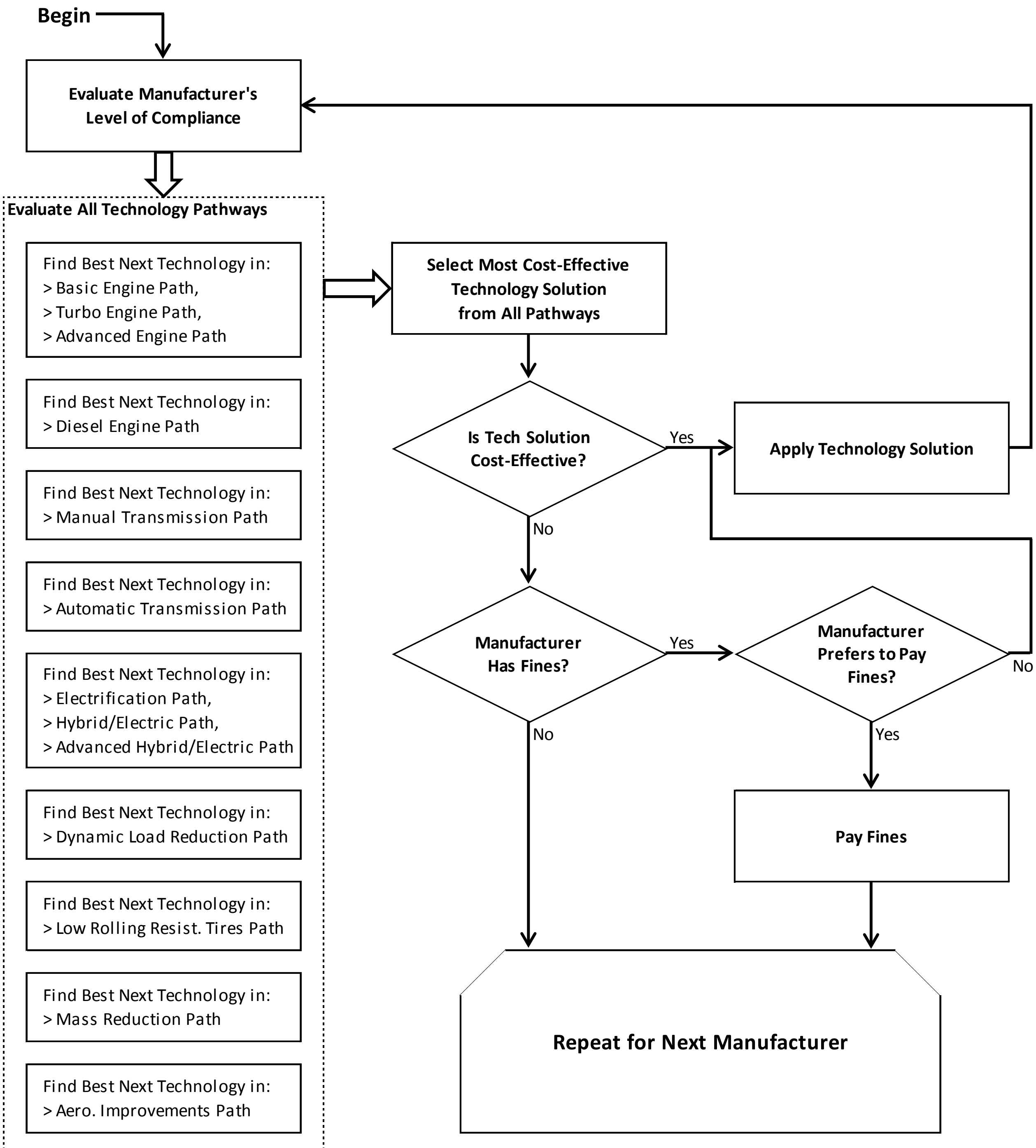

Figure 7. Compliance Simulation Algorithm

Whether or not the manufacturer is assumed to be willing to pay CAFE penalties, the algorithm uses CAFE penalties 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 evaluating the relative attractiveness of different technology applications, not for actual cost accounting. The calculation can span multiple modeling years. For example, if the candidate technology was enabled for application in a previous year and not used, then it can remain as a candidate to be applied and then carried forward to the current model year. The effective cost obtained from application of a set of one or more candidate technologies on a cohort of vehicles *k* is defined by the following formula:

$$COST_{eff} = \frac{\sum_{i\in k}\left(\sum_{j=BaseMY}^{j=MY} TECHCOST_{i,j} - TECHVALUE_{i,j} - (VALUE_{FUEL})_{i,j}\right) + \Delta FINE_{MY}}{TOTALSALES} \quad \textbf{(5)}$$

Where:

MY	:	the model year being analyzed for compliance,
BaseMY	:	the first model year of the potential application of candidate technologies (can be less than or equal to *MY*),
$TECHCOST_{i,j}$	:	the total cost off all candidate technologies evaluated on vehicle *i* in model year *j*,
$TECHVALUE_{i,j}$	:	the net change in consumer valuation of all candidate technologies evaluated on vehicle *i* in model year *j*,
$(VALUE_{FUEL})_{i,j}$	:	the value of the reduction in fuel consumption resulting from application off all candidate technologies evaluated on vehicle *i* in model year *j*,
$\Delta FINE_{MY}$	:	the reduction in manufacturer's fines in the analysis year *MY* (or zero, if the manufacturer prefers not to pay fines or the compliance scenario being evaluated does not allow fine payment for a specific regulatory class), and
TOTALSALES	:	the total sales volume of all affected vehicles in cohort *k* covering model years between *BaseMY* and *MY*.

The value of the reduction in fuel consumption achieved by applying a set of candidate technologies in question to a specific vehicle is calculated as follows:[10]

$$VALUE_{FUEL} = \sum_{FT}\left[\left(\sum_{v=0}^{v=PB}\frac{SURV_v \times VMT_v \times (VMT_{GROWTH})_{(MY+v)} \times (PRICE_{FT})_{MY}}{(1-GAP_{FT})\times(1+r)^v}\right)\times\left(\frac{FS_{FT}}{FE_{FT}} - \frac{FS'_{FT}}{FE'_{FT}}\right)\right] \quad \textbf{(6)}$$

[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, which is regulated as a passenger car, and a minivan, which is regulated as a light truck. If the manufacturer's passenger car fleet complies with the corresponding standard, the algorithm accounts for the fact that upgrading this engine will incur costs and realize fuel savings for both of these vehicle models, but will only yield reductions of CAFE fines for the light truck fleet.

[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.

Where:

FT	: the fuel type the vehicle operates on (gasoline, e85, diesel, electricity, hydrogen, or CNG),
PB	: a "payback period", or number of years in the future the consumer is assumed to take into account when considering fuel savings,
$SURV_v$	: the probability that a vehicle of a given vintage v will remain in service,
VMT_v	: the average number of miles driven in a year by a vehicle at a given vintage v,
$(VMT_{GROWTH})_{MY+v}$	: the growth factor to apply to the base miles driven in the current model year MY at the given vintage v,
$(PRICE_{FT})_{MY}$	: the price of the specific fuel type in year MY,
GAP_{FT}	: the relative difference between on-road and laboratory fuel economy for a specific fuel type,
r	: the discount rate the consumer is assumed to take into account when considering fuel savings,
FE_{FT} and FE'_{FT}	: the vehicle's fuel economy for a specific fuel type prior to and after the pending application of technology, and
FS_{FT} and FS'_{FT}	: the vehicle's assumed share of operating on a specific fuel type prior to and after the pending application of technology.

As discussed in Section A.3 of Appendix A, $SURV_v$, VMT_v, $(VMT_{GROWTH})_{MY+v}$, $(PRICE_{FT})_{MY}$, and GAP_{FT} are all specified in the parameters input file, while the values for r and PB are specified in the market data input file (see Section A.1.1 in Appendix A).

In equation (5), $\Delta FINE$ is the change in total CAFE penalties (*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] The change in fines is calculated by evaluating the following before and after the pending technology application, and taking the difference between the results:

$$FINE = \sum_{C} -k_{F,C} \times \mathrm{MIN}(CREDIT_C + CREDITIN_C - CREDITOUT_C, 0) \qquad (7)$$

Here, $k_{F,C}$ is in dollars per one credit of shortfall and specified in the scenarios input file.

Within each regulatory class C, the amount of CAFE credit created (noncompliance causes credit creation to be negative, which implies the use of CAFE credits or the payment of CAFE penalties) is calculated by taking the difference between the CAFE level achieved by the class and the standard applicable to the class, and multiplying the result by the number of vehicles in that class. Taking into account attribute-based CAFE standards, for light duty regulatory classes, this is expressed as follows:

[11] Exceptions can occur, for example, if mass reduction is applied under a CAFE system in which attribute standards are weight-based rather than footprint-based.

$$CREDIT_C = [\text{ROUND}(CAFE_C(\boldsymbol{V}_C), 1) - STD_C(\boldsymbol{V}_C)] \times N_C \times 10 \qquad \textbf{(8)}$$

While for the class 2b and class 3 regulatory classes, credits are computed as:

$$CREDIT_C = \left[\frac{100}{STD_C(\boldsymbol{V}_C)} - \text{ROUND}\left(\frac{100}{CAFE_C(\boldsymbol{V}_C)}, 2\right)\right] \times N_C \times 100 \qquad \textbf{(9)}$$

Where:

$\boldsymbol{V}_C$: a vector containing all vehicle models in regulatory class C,
$CAFE_C(\boldsymbol{V}_C)$: the CAFE level for regulatory class C,
$STD_C(\boldsymbol{V}_C)$: a function defining the standard applicable to regulatory class C, and
N_C : the total sales volume for regulatory class C.

Additionally, in equation (7) above, $CREDITIN_C$ is the amount of CAFE credit transferred into regulatory class C from another compliance category, while $CREDITOUT_C$ is the amount of CAFE credit transferred out of regulatory class C into another compliance category.

In order to obtain updated credits, and thereby change in fines, due to application of new technology, for each regulatory class C, the values for the CAFE level (or the achieved fuel economy level) and the standard (or the required fuel economy level) are calculated before, during, and after evaluation of each successive technology application. The CAFE level is computed by taking a sales-weighted harmonic average of the individual fuel economies attained by each vehicle model i in a cohort of vehicle k. The following equation presents the calculation of the achieved CAFE level for regulatory class C:

$$CAFE_C(\boldsymbol{V}_C) = \frac{\sum_{i \in k} SALES_i}{\sum_{i \in k} \frac{SALES_i}{FE_i}} \qquad \textbf{(10)}$$

Where:

$\boldsymbol{V}_C$: a vector containing all vehicle models in regulatory class C,
$SALES_i$: the sales volume for a vehicle model i, and
FE_i : the fuel economy (in mpg) attained by a vehicle model i.

Similarly, the value of the standard applicable to regulatory class C is calculated using a sales-weighted harmonic average of the fuel economy targets applicable to each vehicle model i in a cohort of vehicles k. This defines the manufacturer's required fuel economy standard for regulatory class C and is represented by the following equation:

$$STD_C(\boldsymbol{V}_C) = \frac{\sum_{i \in k} SALES_i}{\sum_{i \in k} \frac{SALES_i}{T_i}} \qquad \textbf{(11)}$$

Where:

$\boldsymbol{V}_C$: a vector containing all vehicle models in regulatory class C,
$SALES_i$: the sales volume for a vehicle model i, and
T_i : the fuel economy target (in mpg) applicable to a vehicle model i.

Equation (11) universally applies to an attributed-based standard (*i.e.*, a functional form where a different fuel economy target is computed for each vehicle based on, for example, its footprint) as well as a flat standard (*i.e.*, a functional form where each vehicle model has the same fuel economy target). However, for a flat standard, since with a common target the sales volumes of individual vehicle models cancel out, equation (11) is reduced to the following:

$$STD_C(\boldsymbol{V}_C) = T_i \tag{12}$$

Figure 8 gives an overview of the logic the algorithm follows in order to identify the best next technology application for each pathway.

Within a given path, the algorithm considers technologies in the order defined by the technology pathways (as discussed above). 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 effective 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 path, and then selects the technology application yielding the lowest effective cost. As discussed above, the algorithm operates subject to expectations of each manufacturer's preference to pay fines and whether a compliance scenario allows fine payment within the regulatory class being evaluated. $COST_{eff}$ is determined, as above, by equations (5), (6), and (7), irrespective of the fine payment settings.

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

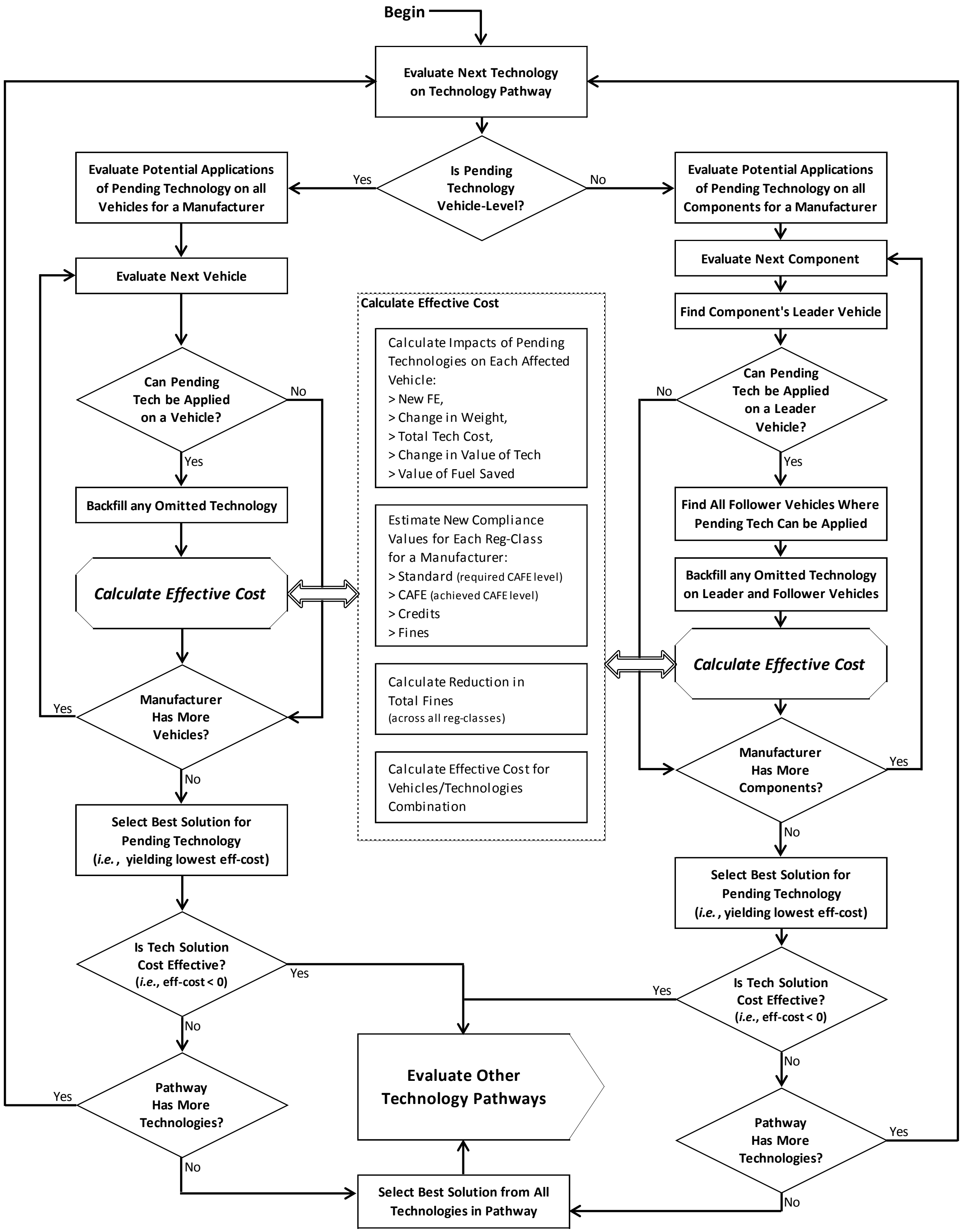

Figure 8. Determination of "Best Next" Technology Application

Note, in the diagram above, a "component" is any platform, engine, or transmission produced by a manufacturer, where application of a technology is evaluated on a vehicle designated as a leader of that component. Any follower vehicles of the same component, for which a candidate technology is available for application in the same analysis step as the leader vehicle, will also be evaluated during technology application.

Chapter Three Calculation of Effects

This chapter describes the way the CAFE modeling system estimates the effects of potential new 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 individual vehicle models that manufacturers make in response to the implosion of higher 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 (or 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 assumed in the CAFE model.[12] Each of the effects of raising CAFE standards is measured by the difference in the value of a variable – such as total gallons of fuel consumed by a vehicle model and vintage over its lifetime – with its baseline fuel economy level, and its estimated fuel economy if that model were instead required to comply with a stricter CAFE standard. A vehicle model's baseline fuel economy level is usually (but not necessarily) defined as the level of fuel economy it would be expected to have if the CAFE standard currently in effect for its vehicle class remained in effect for the future model year when it is produced.

Although these effects are calculated for individual vehicle models, vintages, and future calendar years over their respective lifetimes, they are typically reported at the aggregate level for all vehicle models in a CAFE regulatory class produced during each model year affected by a proposed standard. Cumulative impacts for each CAFE regulatory class and model year over its expected life span are reported both in undiscounted terms and as their present value discounted to the calendar year defined within the parameters input file.

[12] We adopt the simplifications that vehicle model years and calendar years are identical, and that all vehicles produced during a model year are sold and placed into service during the corresponding calendar year.

Section 1 Vehicle Lifetimes

The number of vehicles of a specific model and model year (or vintage) that remains in service during each subsequent calendar year is calculated by multiplying the number originally produced by estimates of the proportion expected to remain in service at each age up to an assumed maximum lifetime. Separate survival rates by age of vehicle were developed for passenger automobiles, light trucks (class 1 and 2a), and medium duty trucks (class 2b and 3), where light trucks are further separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A. Thus, the number of vehicles of model *i* produced during model year *MY*, and belonging to survival category *C*, which remain in use during a future calendar year *CY* is defined by the following equation:

$$N_{i,MY,CY} = SURV_{C,a} \times N_{i,MY} \tag{13}$$

Where

- $SURV_{C,a}$: the probability that vehicles belonging to a specific category *C* will remain in service at a given age *a*,
- $N_{i,MY}$: the forecast number of new vehicles of a specific vehicle model *i* produced and sold during a given model year *MY*, and
- $N_{i,MY,CY}$: the number of vehicles of model *i* produced during model year *MY* that remain in use during a future calendar year *CY*.

The age of a vehicle model produced in model year *MY* during calendar year *CY* is defined as:

$$a = CY - MY \tag{14}$$ [13]

The CAFE model currently accommodates different schedules of survival rates by vehicle age for varying vehicle classes, where class 1/2a light trucks are further separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A. Based on analysis of recent registration data, the maximum ages of passenger automobiles and light and medium duty trucks are estimated to be 30 years and 37 years, respectively.[14]

Each vehicle model *i* produced during a model year *MY* is designated as operating on a specific fuel type or employing a specific technology; all units of that model produced during a model year are assumed to be of the same fuel or technology type. The CAFE model currently recognizes seven fuel or technology types: gasoline, diesel, compressed natural gas, flexible-fuel vehicles (or FFVs, which are capable of operating on gasoline or on gasoline blended with up to

[13] We define a vehicle's age to be 0 during the year when it is produced and sold; that is, when *CY*=*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 depends only on the difference between its model year (*MY*) and the calendar year (*CY*) for which these calculations are performed, and not on their specific values.

[14] These are defined as the ages when the number of vehicles of a model year that remain in service has declined to fewer than 2% of those originally produced.

85% ethanol), plug-in hybrid electric vehicles (or PHEVs, which can operate on either gasoline or electricity generated off-board and stored in on-board batteries), electric vehicles (or EVs, which operate only on electricity generated off-board and stored in on-board batteries), and fuel cell vehicles (or FCVs, which use fuel cells to power on-board electric motors using compressed hydrogen gas). The fractions of total mileage for which FFVs operate on gasoline and ethanol-blend fuels, and the fractions of total mileage for which PHEVs operate on gasoline and stored electricity, are inputs to the model.

Section 2 Vehicle Use and Total Lifetime Mileage

The CAFE model employs the widely documented relationship between vehicle age and declining average vehicle use to estimate the number of miles that individual vehicle models are driven annually and in total over their expected lifetimes. Separate schedules of average annual miles driven by age of vehicle were developed for passenger automobiles, light trucks (class 1 and 2a), and medium duty trucks (class 2b and 3), where light trucks are further separated into vans, SUVs, and pickups, as reported in Section A.3.1 of Appendix A.

Two adjustments are applied to these mileage schedules to forecast the average number of miles that vehicles produced during future model years will be driven each year over their expected lifetimes. First, the estimates of annual miles driven by passenger cars and trucks are adjusted to reflect assumed future growth in average vehicle use.[15] Second, the estimates of average annual miles driven by cars and trucks of each age are further adjusted by applying the estimated elasticity of vehicle use with respect to fuel cost per mile to the difference in inflation-adjusted fuel price per gallon between the base calendar year, when the VMT survey was taken, and each subsequent calendar year. This adjustment employs a combination of actual historic fuel prices for the calendar years prior to start of the modeling analysis, forecasts for calendar years as reported in the U.S. Energy Information Administration's Annual Energy Outlook (AEO), and extrapolations of gasoline prices beyond the last year provided by AEO. The elasticity (or a fuel economy rebound effect) as well as the VMT growth assumptions are provided as inputs to the model and are further described in Section A.3.4 of Appendix A.

The average number of miles driven by a surviving vehicle model *i* produced in model year *MY*, and belonging to VMT category *C*, during calendar year *CY* is given by:

$$MI_{i,MY,CY} = VMT_{C,a} \times (1+r)^{CY-BaseCY} \times \left[1 + \varepsilon \times \left(\frac{CPM_{i,MY,CY}}{CPM_{H,a,BaseCY}} - 1\right)\right] \quad \textbf{(15)}$$

Where:

$VMT_{C,a}$	:	the average annual miles that vehicles belonging to a specific category *C* drive at a given age *a*,
BaseCY	:	the base calendar year for VMT usage data corresponding to the year when the VMT survey was taken,
r	:	the rate of growth in VMT per vehicle beginning in the base year *BaseCY*,
ε	:	the elasticity of annual vehicle use with respect to fuel cost per mile,
$CPM_{i,MY,CY}$	:	the fuel cost per mile of a vehicle model *i* produced in model year MY during calendar year *CY*,

[15] Increases in the average number of miles cars and trucks are driven each year have been an important source of historical growth in *total* car and truck use, and are expected to represent an important source of future growth in total light-duty vehicle travel as well.

$CPM_{H,a,BaseCY}$: the average fuel cost per mile of all historic vehicles that were age *a* during the base calendar year *BaseCY*, and

$MI_{i,MY,CY}$: the resultant number of miles driven in a year by a vehicle model *i* produced in model year *MY* during calendar year *CY*.

The value of fuel cost per mile for vehicle model *i* depends on both the price per gallon of fuel (or gasoline gallon equivalent, GGE, in the case of electricity, hydrogen, and CNG) during calendar year *CY* as well as the actual fuel economy that vehicle *i* of model year *MY* achieves in on-road driving. For most vehicles that operate exclusively on a single fuel type (typically, gasoline or diesel) the cost per mile is calculated from just that one fuel component. However, for dual fuel vehicles (such as PHEVs and FFVs), the cost per mile is a weighted sum of individual fuel components on which the vehicle operates. The cost per mile for vehicle model *i* produced in model year *MY* during each calendar year *CY* is hence defined by the following equation:

$$CPM_{i,MY,CY} = \sum_{FT} \frac{(PRICE_{FT})_{CY}}{FE_{i,MY,FT} \times (1 - GAP_{FT})} \times FS_{i,MY,FT} \qquad \textbf{(16)}$$

Where:

FT : the fuel type the vehicle model *i* operates on (gasoline, e85, diesel, electricity, hydrogen, or CNG) in model year *MY*,

$(PRICE_{FT})_{CY}$: the inflation-adjusted price per gallon (or per GGE) of the specific fuel type in calendar year *CY*,

$FE_{i,MY,FT}$: the rated fuel economy a vehicle model *i* achieves during model year *MY* when operating on a specific fuel type *FT*,

$FS_{i,MY,FT}$: the percentage share of miles a vehicle model *i* produced during model year *MY* travels when operating on a specific fuel type *FT*, and

GAP_{FT} : the relative difference between on-road and laboratory fuel economy for a specific fuel type.

Each model's rated fuel economy is assumed to be determined during the model year when it is produced, and to remain fixed throughout its lifetime. However, its actual on-road fuel economy is assumed to fall short of that rating by the on-road fuel economy "gap" (a model input specified in the parameters input file).

Similar to the cost per mile equation for a vehicle model *i*, the value of fuel cost per mile averaged across all historic vehicles *H* that were age *a* during the calendar year *BaseCY* when the VMT survey was taken is represented by the following equation:

$$CPM_{H,a,BaseCY} = \sum_{FT} \frac{(PRICE_{FT})_{BaseCY}}{FE_{BaseCY-a,FT} \times (1 - GAP_{FT})} \times FS_{BaseCY-a,FT} \qquad \textbf{(17)}$$

Where:

BaseCY	:	the base calendar year for VMT usage data corresponding to the year when the VMT survey was taken,
BaseCY – a	:	the model year during which the historic vehicles were produced when they were age *a* in the base calendar year *BaseCY*,
FT	:	the fuel type that historic vehicles *h* operated on (gasoline, e85, diesel, electricity, hydrogen, or CNG) in model year *BaseCY – a*,
$(PRICE_{FT})_{BaseCY}$	:	the inflation-adjusted price per gallon (or GGE) of the specific fuel type in the calendar year *BaseCY*,
$FE_{BaseCY\text{-}a,FT}$	:	the sales-weighted average fuel economy that all historic vehicles achieved in model year *BaseCY – a* for a specific fuel type *FT*,
$FS_{BaseCY\text{-}a,FT}$	:	the percentage share of total miles that all historic vehicles traveled in model year *BaseCY – a* when operating on a specific fuel type *FT*, and
GAP_{FT}	:	the relative difference between on-road and laboratory fuel economy for a specific fuel type.

Since the mileage accumulation schedule used in equation (15) is based on the VMT survey that was conducted during the calendar year *BaseCY*, the elasticity of annual vehicle use correlates the cost per mile of a new vehicle model of age *a* during each calendar year *CY* to the cost per mile of a typical historic vehicle that was of the same age during the base calendar year *BaseCY*. The CPM of a historic vehicle is hence calculated using the fuel prices of the base VMT calendar year, while the CPM of a new vehicle model is obtained using the fuel price forecasts in the calendar years corresponding to the vehicle's model year and age. This relationship between the new and existing vehicles reflects the fuel economy rebound effect, which occurs because buyers of new vehicles respond to the reduction in their operating costs—resulting from higher fuel economy of new vehicles—by driving slightly more during a particular calendar year.

Equation (15) specifies the average number of miles driven by a single surviving vehicle model *i* produced in model year *MY* during calendar year *CY*. The total number of miles driven by all vehicles of a specific model *i* and model year *MY* during each calendar year they remain in the fleet is then calculated by multiplying the appropriate estimate of annual miles driven per vehicle by the number of vehicles of that model year remaining in service during that calendar year. Thus, the total miles driven during calendar year *CY* by the surviving vehicles of model *i* that were originally produced during model year *MY* is calculated as:

$$MI'_{i,MY,CY} = N_{i,MY,CY} \times MI_{i,MY,CY} \quad \textbf{(18)}$$

Where:

$N_{i,MY,CY}$	:	the number of vehicles of model *i* produced during model year *MY* that remain in use during a future calendar year *CY* as defined in equation (13) above,
$MI_{i,MY,CY}$	:	the number of miles driven in a year by a single vehicle model *i* as defined in equation (15) above, and
$MI'_{i,MY,CY}$	:	the resultant number of miles driven in a year by all surviving vehicles of model *i* produced in model year *MY* during calendar year *CY*.

Section 3 Fuel Consumption and Savings

Fuel consumption by vehicles of each model and vintage during a future year depends on the total mileage that the surviving vehicles are driven during that year, as well as on the fuel efficiency they obtain in actual driving. As indicated previously, the fuel economy levels that new vehicles achieve in real-world driving falls significantly short of the rated fuel economy levels that are used to assess manufacturers' compliance with CAFE standards.

The number of gallons of each type of fuel (or GGE for electricity, hydrogen, and CNG) consumed by a surviving vehicle of model *i* produced in model year *MY* during calendar year *CY* is calculated as shown in the following equation:

$$G_{i,MY,CY,FT} = \frac{MI_{i,MY,CY}}{FE_{i,MY,FT} \times (1 - GAP_{FT})} \times FS_{i,MY,FT} \tag{19}$$

Where:

- FT : the fuel type the vehicle model *i* operates on (gasoline, e85, diesel, electricity, hydrogen, or CNG) in model year *MY*,
- $MI_{i,MY,CY}$: the number of miles driven in a year by a vehicle model *i* produced in model year *MY* during calendar year *CY*, as defined in equation (15) above,
- $FE_{i,MY,FT}$: the rated fuel economy a vehicle model *i* achieves during model year *MY* when operating on a specific fuel type *FT*,
- $FS_{i,MY,FT}$: the percentage share of miles a vehicle model *i* produced during model year *MY* travels when operating on a specific fuel type *FT*,
- GAP_{FT} : the relative difference between on-road and laboratory fuel economy for a specific fuel type, and
- $G_{i,MY,CY,FT}$: the resultant number of gallons of fuel consumed in a year by a vehicle model *i* produced in model year *MY* during calendar year *CY*, when operating on a specific fuel type *FT*.

As equation (19) indicates, many of the factors determining a vehicle model's consumption of different fuels can vary depending on the CAFE standard that is in effect during the model year it is produced. Specifically, the shares of miles for which it operates on different fuels, its fuel economy when using each different fuel, and as discussed previously, its average annual mileage can each differ between the baseline market forecast and any alternative CAFE level that the model is used to analyze. These differences occur because manufacturers will increase the fuel economy of some models in response to increases in CAFE standards from their baseline level, and may convert some gasoline-powered models to diesels, PHEVs, or EVs.

Similar to the mileage accumulation equations discussed in the previous section, the fuel consumption equation above estimates the amount of gallons consumed by a single vehicle model *i* of model year *MY* during calendar year *CY*. The total amount of gallons (or GGE) consumed by all surviving vehicles of model *i* and model year *MY* during calendar year *CY* is then defined as follows:

$$G'_{i,MY,CY,FT} = N_{i,MY,CY} \times G_{i,MY,CY,FT} \quad \textbf{(20)}$$

Where:

- $N_{i,MY,CY}$: the number of vehicles of model *i* produced during model year *MY* that remain in use during a future calendar year *CY* as defined in equation (13) above,
- $G_{i,MY,CY,FT}$: the amount of gallons of fuel consumed in a year by a single vehicle model *i* as defined in equation (19) above, and
- $G'_{i,MY,CY,FT}$: the resultant amount of gallons of fuel consumed in a year by all surviving vehicles of model *i* produced in model year *MY* during calendar year *CY*, when operating on a specific fuel type *FT*.

From here, the total fuel consumption for each fuel type of all surviving vehicles of model *i* and model year *MY* over their expected lifetimes may be obtained by summing the amount of gallons consumed across the individual calendar years as such:

$$G'_{i,MY,FT} = \sum_{CY} G'_{i,MY,CY,FT} \quad \textbf{(21)}$$

The calendar year *CY* in the equation above ranges between the model year *MY* when the vehicle model *i* was produced until *MY* plus the maximum survival age of that vehicle.

Although the modeling system calculates fuel consumption for each individual vehicle model, it aggregates these results across all vehicle models for reporting purposes. The total consumption of each type of fuel by all vehicle models produced in model year *MY* during calendar year *CY* is calculated by summing the fuel consumptions of each individual vehicle model *i* in a cohort of vehicles *k* as shown in the following equation:

$$GALLONS_{MY,CY,FT} = \sum_{i \in k} G'_{i,MY,CY,FT} \quad \textbf{(22)}$$

Similarly, the total consumption of each type of fuel by all vehicle models produced in model year *MY* over their expected lifetimes is calculated by summing the total lifetime fuel consumptions of each vehicle model *i* as follows:

$$GALLONS_{MY,FT} = \sum_{i \in k} G'_{i,MY,FT} \quad \textbf{(23)}$$

As with annual consumption of different types of fuels by individual vehicle models, total annual consumption of each fuel by all vehicle models will differ depending on the CAFE standard that prevailed during the model year when they were originally produced. 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.

The usual assumption employed in the CAFE model is that the baseline fuel economy levels for vehicles produced during a future model year would be those that manufacturers would provide if the most recently adopted standard was extended to apply to future model years. Thus, for example, the baseline fuel economy levels projected for vehicles produced during some future model years are estimated under the assumption that the recently adopted CAFE standards for model year 2016 (as an example) cars and light trucks would be extended to apply to those future model years. Estimated fuel consumption with the 2016 CAFE standard assumed to remain in effect for model years after 2016 provides the baseline for measuring reductions in fuel use expected to result from adopting higher CAFE standards in the future model years.

The savings in total consumption of each type of fuel by all vehicle models produced during a model year *MY* over their expected lifetimes is computed as:

$$\Delta GALLONS_{MY,FT} = \left(GALLONS_{MY,FT}\right)_{CAFE} - \left(GALLONS_{MY,FT}\right)_{Baseline} \quad \textbf{(24)}$$

Where:

$(GALLONS_{MY,FT})_{CAFE}$	:	the total fuel consumption by all vehicle models produced during model year *MY* over their expected lifetimes, for each fuel type *FT*, resulting from increases in vehicle fuel economy as a response to the new *CAFE* standards,
$(GALLONS_{MY,FT})_{Baseline}$	:	the total fuel consumption by all vehicle models produced during model year *MY* over their expected lifetimes, for each fuel type *FT*, assuming the *baseline* standards stay in place during a future model year *MY*, and
$\Delta GALLONS_{MY,FT}$	:	the changes in fuel consumption for each fuel type *FT* resulting from average increases in vehicle's fuel economies due to higher *CAFE* standards relative to the baseline fuel economy levels.

In addition to calculating fuel consumption in terms of amount of gallons (or GGE) consumed for each fuel type, the modeling system also calculates corresponding energy consumption in quadrillion British thermal units (or Quads) attributable to each fuel type analyzed within the model, reporting these quantities on a total and incremental basis. For non-liquid fuel types (electricity, hydrogen, and CNG), the CAFE model also estimates energy consumption in native units of that fuel type (kilowatt-hours, or kWh, for electricity and standard cubic feet, or scf, for hydrogen and CNG).[16]

For liquid fuel types (gasoline, e85, and diesel), the conversion of energy consumption to quadrillion BTUs is calculated within the model by simply multiplying the amount of gallons of the specific fuel consumed by the energy density of that fuel type and scaling the result from BTUs to Quads. The system computes amount of Quads consumed by each individual vehicle

[16] When reporting amounts of fuel and energy consumption, the system converts all units into thousands. Thus, liquid fuel consumed is reported in thousands of gallons, electricity in mW-h, and hydrogen and CNG in Mcf.

model as well as overall consumption across all surviving vehicle models, for any given calendar year and/or model year. Thus, the equation for calculating Quads takes general form as shown:

$$QUADS_{FT} = \frac{GALLONS_{FT} \times ED_{FT}}{1e15} \quad \textbf{(25)}$$

Where:

$GALLONS_{FT}$: the amount of gallons of fuel type *FT* consumed by one or more vehicle models,
ED_{FT} : the energy density of fuel type *FT*, and
$QUADS_{FT}$: the energy consumption expressed quadrillion BTUs for fuel type *FT*.

For electricity, hydrogen, and CNG fuel types, since their consumption is measured in gasoline gallon equivalents, the conversion to Quads is calculated by multiplying the amount of GGE by the energy density of gasoline. Equation (25) above then becomes:

$$QUADS_{FT} = \frac{GALLONS_{FT} \times ED_{Gasoline}}{1e15} \quad \textbf{(26)}$$

Additionally for electricity, hydrogen, and CNG, the conversion from GGE to native units (kWh or scf) is calculated by multiplying the amount of gallons consumed by the ratio of the energy density of gasoline to the energy density of a specific fuel type. As with the calculation of energy use in Quads, the system computes consumption of kilowatt-hours and standard cubic feet for each individual vehicle model and total consumption for all surviving vehicle models. Hence, for electricity, the equation is defined as:

$$KWH = GALLONS_{FT} \times \frac{ED_{Gasoline}}{ED_{FT}} \quad \textbf{(27)}$$

While for hydrogen and CNG, the equation is as follows:

$$SCF = GALLONS_{FT} \times \frac{ED_{Gasoline}}{ED_{FT}} \quad \textbf{(28)}$$

Where:

$GALLONS_{FT}$: the amount of gasoline gallon equivalents of *Electricity*, *Hydrogen*, or *CNG* fuel types (denoted by the *FT* subscript) consumed by one or more vehicle models,
$ED_{Gasoline}$: the energy density of gasoline fuel,
ED_{FT} : the energy density of *Electricity*, *Hydrogen*, or *CNG* fuel types,
KWH : the amount of kilowatt-hours of *Electricity* fuel type consumed by one or more vehicle models (equation (27)), and
SCF : the amount of standard cubic feet of *Hydrogen* or *CNG* fuel types consumed by one or more vehicle models (equation (28)).

Section 4 Greenhouse Gas Emissions

Fuel savings from imposing stricter CAFE standards will result in lower emissions of carbon dioxide (CO_2), the primary greenhouse gas emitted during the refining, distribution, and combustion of transportation fuels. Lower fuel consumption reduces carbon dioxide emissions directly, because the largest source of these emissions from transportation activity is fuel used by internal combustion engines. The CAFE model calculates CO_2 emissions from vehicle operation by multiplying the number of gallons of a specific fuel consumed (gasoline, e85, or diesel) by the carbon content per gallon of that fuel type, and then applying the ratio of carbon dioxide emissions generated per unit of carbon consumed during the combustion process.[17]

Emissions of carbon dioxide resulting from fuel consumption by all surviving vehicle models produced in model year *MY* during calendar year *CY* are calculated from their consumption of each individual fuel type as:

$$CO2^{veh}_{MY,CY} = \frac{\sum_{FT}\left(GALLONS_{MY,CY,FT} \times MD_{FT} \times C_{FT}\right) \times \left({}^{44}/_{12}\right)}{1e6} \quad \textbf{(29)}$$

Where:

$GALLONS_{MY,CY,FT}$	:	the amount of gallons of fuel consumed in a year by all surviving vehicle models produced in model year *MY* during calendar year *CY*, for a specific fuel type *FT*,
MD_{FT}	:	the mass density of a fuel type *FT* (an input parameter specified in grams per unit of fuel type, which is either gallons, kWh, or scf),
C_{FT}	:	the fraction of each fuel type's mass that represents carbon,
$({}^{44}/_{12})$	:	the ratio of the molecular weight of carbon dioxide to that of elemental carbon[18],
$1e6$	:	the conversion factor from grams to metric tons, and
$CO2^{veh}_{MY,CY}$	:	the total emissions of carbon dioxide (denominated in metric tons) resulting from fuel consumption by all surviving vehicle models produced in model year *MY* during calendar year *CY* aggregated for all fuel types.

Vehicles operating on electricity or hydrogen are assumed to generate no CO_2 emissions during vehicle use. For vehicles operating on CNG, since mass density is specified in grams per scf, the

[17] The carbon content for each type of fuel is specified as an input to the model in the parameters input file (further discussed in Section A.3.11 of Appendix A). Although the model 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). Since electricity and hydrogen fuel types do not cause CO_2 emissions to be emitted during vehicle operation, the carbon content for these fuel types should be set to zero in the input file.

[18] This ratio measures the mass of carbon dioxide that is produced by complete combustion of mass of carbon contained in each gallon of fuel.

generated CO_2 emissions are calculated using amount of scf of CNG instead of amount of gallons consumed by all vehicle models. Thus, equation (29) above becomes:

$$CO2_{MY,CY}^{veh} = \frac{\sum_{FT}\left(SCF_{MY,CY,FT} \times MD_{FT} \times C_{FT}\right) \times \left({}^{44}/_{12}\right)}{1e6} \quad (30)$$

As with the model's calculations of fuel consumption, estimates of annual CO_2 emissions from fuel use are summed over the calendar years that vehicles produced during each model year are projected to remain in use to obtain estimates of lifetime emissions. Specifically, lifetime CO_2 emissions from fuel consumption by vehicle models produced during model year *MY* is defined by the following:

$$CO2_{MY}^{veh} = \sum_{CY} CO2_{MY,CY}^{veh} \quad (31)$$

By reducing the volume of fuel consumed, raising CAFE standards will also affect carbon dioxide emissions from refining and distributing liquid fuels (gasoline, diesel, and e85). Carbon dioxide emissions occur during the production of petroleum-based fuels as a result of energy use for petroleum extraction, transportation, storage, and refining, as well as during storage and distribution of refined fuel. Producing the chemical feedstocks or agricultural products from which non-petroleum fuels such as ethanol are derived also entails energy use and generates CO_2 emissions, as does refining, storing, and distributing those fuels. Generating electricity for use by PHEVs and EVs, or hydrogen for use by FCVs, using fossil energy sources such as coal or natural gas also produces CO_2 emissions. Additionally, extracting natural gas from wells, as well as production (consisting of compression, cooling, and dehydration) and storage of CNG, also produces CO_2 emissions.

The CAFE model calculates reductions in carbon dioxide emissions from each stage of fuel production and distribution using aggregate estimates of emissions from all stages of these processes per unit of fuel energy supplied. These estimates are first converted to grams per quadrillion BTUs, then multiplied by the amount of Quads of each fuel type consumed to estimate total carbon dioxide emissions from production and distribution of various fuel types. Hence, the total CO_2 emissions resulting from producing and distributing of fuel consumed by all surviving vehicles of model year *MY* during calendar year *CY* is given by:

$$CO2_{MY,CY}^{ref} = \frac{\sum_{FT}\left(QUADS_{MY,CY,FT} \times CO2_{FT} \times 1e9\right)}{1e6} \quad (32)$$

Where:

$QUADS_{MY,CT,FT}$: the amount of quadrillion BTUs of energy consumed in a year by all surviving vehicle models produced in model year *MY* during calendar year *CY*, for a specific fuel type *FT*,

$CO2_{FT}$: overall emissions of carbon dioxide from all stages of feedstock production and distribution of fuel type *FT* (an input parameter specified in grams per million-Btu; the input value is multiplied by 1*e*9 in order to convert it into grams per Quad),

1*e*6 : the conversion factor from grams to metric tons, and

$CO2^{ref}_{MY,CY}$: the total emissions of carbon dioxide (denominated in metric tons) resulting from production and distribution of various fuel types used by all surviving vehicle models produced in model year *MY* during calendar year *CY*.

Annual CO_2 emissions generated by fuel production and distribution are then summed over the lifetimes of all vehicle models produced during each model year *MY* as such:

$$CO2^{ref}_{MY} = \sum_{CY} CO2^{ref}_{MY,CY} \quad \textbf{(33)}$$

Finally, CO_2 emissions from fuel consumption are combined with emissions generated during the fuel supply process to yield total CO_2 emissions from fuel production and consumption by vehicles produced during a model year over their expected lifetimes, and are defined as such:

$$CO2^{tot}_{MY} = CO2^{veh}_{MY} + CO2^{ref}_{MY} \quad \textbf{(34)}$$

Since imposing a higher CAFE standard in a given model year reduces the overall fuel consumption over the lifetimes of all vehicles produced during that year, and since CO_2 emissions are a direct product of the volume of fuel produced and consumed, imposing a higher CAFE standard also reduces the lifetime CO_2 emissions. The model estimates this reduction in CO_2 emissions by taking the difference between the total lifetime emissions of all vehicle models produced in a model year with the new CAFE standard in effect and their total lifetime emissions with the baseline standard in effect. This calculation is defined by the following equation:

$$\Delta CO2_{MY} = (CO2_{MY})_{CAFE} - (CO2_{MY})_{Baseline} \quad \textbf{(35)}$$

Where:

$(CO2_{MY})_{CAFE}$: the total emissions of carbon dioxide generated from production and consumption of various fuel types by all vehicle models produced during model year *MY* over their expected lifetimes, resulting from increases in vehicle fuel economy as a response to the new *CAFE* standard,

$(CO2_{MY})_{Baseline}$: the total emissions of carbon dioxide generated from production and consumption of various fuel types by all vehicle models produced during model year *MY* over their expected lifetimes, assuming the *baseline* standard stay in place during a future model year *MY*, and

$\Delta CO2_{MY}$: the changes in total emissions of carbon dioxide resulting from average increases in vehicle's fuel economies due to higher *CAFE* standards relative to the baseline fuel economy levels.

Section 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 also emitted during the production and distribution of fuel. Criteria pollutants that are emitted in significant quantities by 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 fuel economy rebound effect causes increased emissions of most criteria pollutants, since federal standards regulate permissible emissions of these pollutants on a per-mile basis. In contrast, reductions in the volume of fuel consumed that result from requiring higher fuel economy cause emissions of criteria pollutants during fuel production and distribution to decline. The net change in total emissions of each criteria pollutant that results from imposing a higher CAFE standard depends on the relative magnitudes of changes in emissions from vehicle use and from fuel refining and distribution.

The CAFE model calculates emissions of criteria pollutants resulting from vehicle operation by multiplying the number of miles driven by vehicles of a model year during each year they remain in service by per-mile emission rates for each pollutant, which are listed in the parameters input file by model year and vehicle age. These emission rates differ among passenger cars, light trucks, and class 2b/3 trucks when operating on different fuel types. The CAFE modeling system accepts emission rate tables defined for gasoline and diesel fuel types, where the gasoline rates are also used for vehicles operating on E85.[19] Additionally, vehicles operating on electricity (PHEVs and EVs), hydrogen (FCV), and CNG are assumed to generate no emissions of criteria air pollutants during vehicle use.

Total emissions of any given criteria air pollutant from the use of all surviving vehicle models produced during model year *MY* during calendar year *CY* is defined as follows:

$$E^{veh}_{MY,CY} = \frac{\sum_i \sum_{FT} MI'_{i,MY,CY} \times FS_{i,MY,FT} \times E_{i,MY,a,FT}}{1e6} \quad \textbf{(36)}$$

Where:

$MI'_{i,MY,CY}$: the number of miles driven in a year by all surviving vehicles of model *i* produced in model year *MY* during calendar year *CY*,

$FS_{i,MY,FT}$: the percentage share of miles a vehicle model *i* produced during model year *MY* travels when operating on a specific fuel type *FT*,

[19] Given that no reliable sources of information for criteria emissions resulting from vehicle operation are available for E85 fuel, and since overall utilization of E85 by all vehicle models is insignificant when compared to overall vehicle fuel consumption, the modeling system assumes a simplification that emissions generated from vehicle operation on E85 fuel are equivalent to that of gasoline.

$E_{i,MY,a,FT}$: the per-mile rate at which vehicles of model i and model year MY emit a given pollutant at age a when operating on a specific fuel type FT,

$1e6$: the conversion factor from grams to metric tons, and

$E^{veh}_{MY,CY}$: the total emissions of a specific pollutant (denominated in metric tons) resulting from fuel consumption by all surviving vehicle models produced in model year MY during calendar year CY aggregated for all fuel types.

As with fuel use and CO_2 emissions, annual emissions of each criteria air pollutant are summed over the calendar years that vehicle models originally produced during each model year are expected to be in service, in order to produce estimates of their total lifetime emissions. Thus, lifetime emissions of each air pollutant is defined as:

$$E^{veh}_{MY} = \sum_{CY} E^{veh}_{MY,CY} \quad \textbf{(37)}$$

Emissions of criteria air pollutants that occur during production and distribution of various fuel types are estimated using the same methodology employed for calculating carbon dioxide emissions, as discussed in the previous section and defined by equation (32) above. The model uses aggregate estimates of emissions of criteria air pollutants from all stages of fuel production and distribution, which are specified in the parameters input file and are weighted by the user-defined fuel import assumptions. Thus, the total emissions of any given criteria air pollutant from producing and distributing of fuel consumed by all surviving vehicle models of model year MY during calendar year CY is:

$$E^{ref}_{MY,CY} = \frac{\sum_{FT}\left(QUADS_{MY,CY,FT} \times E_{FT} \times 1e9\right)}{1e6} \quad \textbf{(38)}$$

Where:

$QUADS_{MY,CT,FT}$: the amount of quadrillion BTUs of energy consumed in a year by all surviving vehicle models produced in model year MY during calendar year CY, for a specific fuel type FT,

E_{FT} : overall emissions of a given pollutant from all stages of feedstock production and distribution of fuel type FT (an input parameter specified in grams per million-Btu; the input value is multiplied by $1e9$ in order to convert it into grams per Quad),

$1e6$: the conversion factor from grams to metric tons, and

$E^{ref}_{MY,CY}$: the total emissions of a specific pollutant (denominated in metric tons) resulting from production and distribution of various fuel types used by all surviving vehicle models produced in model year MY during calendar year CY.

Emissions of each criteria pollutant attributable to producing and distributing the fuel consumed over the lifetimes of all vehicle models produced during model year MY are summed to obtain:

$$E_{MY}^{ref} = \sum_{CY} E_{MY,CY}^{ref} \tag{39}$$

Finally, total emissions of each criteria pollutant over the lifetimes of all vehicles of model year *MY* are the sum of emissions that occur as a result of their lifetime use, and emissions from producing and distributing the fuel they consume over their lifetimes, which is given by:

$$E_{MY}^{tot} = E_{MY}^{veh} + E_{MY}^{ref} \tag{40}$$

As with the emissions of carbon dioxide, total lifetime emissions of each criteria air pollutant by all vehicles produced during a future model year will differ between the baseline CAFE standard and any alternative standard that is specified. The model calculates the effect of imposing a higher CAFE standard on emissions of criteria air pollutants by taking the difference between lifetime emissions by all vehicle models produced during a model year the new CAFE standard takes effect and those vehicles' emissions under the baseline standard. This calculation is defined as:

$$\Delta E_{MY} = (E_{MY})_{CAFE} - (E_{MY})_{Baseline} \tag{41}$$

Where:

$(E_{MY})_{CAFE}$	:	the total emissions of a specific pollutant generated from production and consumption of various fuel types by all vehicle models produced during model year *MY* over their expected lifetimes, resulting from increases in vehicle fuel economy as a response to the new *CAFE* standard,
$(E_{MY})_{Baseline}$	:	the total emissions of a specific pollutant generated from production and consumption of various fuel types by all vehicle models produced during model year *MY* over their expected lifetimes, assuming the *baseline* standard stay in place during a future model year *MY*, and
ΔE_{MY}	:	the changes in total emissions of a specific criteria air pollutant resulting from average increases in vehicle's fuel economies due to higher *CAFE* standards relative to the baseline fuel economy levels.

Section 6 Vehicle Safety Effects

As discussed in Section 2 above, vehicle miles traveled may increase due to the fuel economy rebound effect, resulting from improvements in vehicle fuel efficiency and cost of fuel, as well as the assumed future growth in average vehicle use. Increases in total lifetime mileage increase exposure to vehicle crashes, including those that result in fatalities. Consequently, the modeling system computes total fatalities attributed to vehicle use for vehicles of model year *MY*, belonging to safety class *SC* and weight threshold *T* as:

$$F_{MY,SC,T} = \frac{VMT_{MY,SC,T}}{1e9} \times BASE_{SC,T} \times FMVSS_{SC,T} \qquad \textbf{(42)}$$

Where:

- $VMT_{MY,SC,T}$: the lifetime vehicle miles traveled for vehicles of model year *MY* within a safety class *SC* and weight threshold *T*,
- $BASE_{SC,T}$: the measure of base fatalities per billion miles for vehicles within a safety class *SC* and weight threshold *T*, and
- $FMVSS_{SC,T}$: an adjustment for new Federal Motor Vehicle Safety Standards (FMVSS) for vehicles within a safety class *SC* and weight threshold *T*.

The $FMVSS_{SC,T}$ adjustment in equation (42) above is employed to account for the fact that vehicles involved in future crashes will be certified to more stringent safety standards than those involved with past crashes upon which the base rates of involvement in fatal crashes were estimated.

Since the use of mass reducing technology is present within the model, safety impacts may also be observed whenever a vehicle's base weight decreases. Thus, in addition to computing total fatalities related to vehicle use, the modeling system also estimates changes in fatalities due to reduction in vehicle's curb weight. These changes are computed for vehicles of model year *MY*, belonging to safety class *SC* and weight threshold *T* as:

$$F^{\Delta CW}_{MY,SC,T} = \frac{VMT_{MY,SC,T}}{1e9} \times \frac{\Delta CW}{100} \times Effect_{SC,T} \times BASE_{SC,T} \times FMVSS_{SC,T} \qquad \textbf{(43)}$$

Where:

- $VMT_{MY,SC,T}$: the lifetime vehicle miles traveled for vehicles of model year *MY* within a safety class *SC* and weight threshold *T*,
- ΔCW : the amount by which the vehicle's curb weight decreases,
- $Effect_{SC,T}$: the percentage by which fatalities change for every 100 lbs. that a vehicle's curb weight is reduced for vehicles within a safety class *SC* and weight threshold *T*,
- $BASE_{SC,T}$: the measure of base fatalities per billion miles for vehicles within a safety class *SC* and weight threshold *T*, and

$FMVSS_{SC,T}$: an adjustment for new FMVSS for vehicles within a safety class *SC* and weight threshold *T*.

Equation (43) is applied directly as long as the vehicle's initial and final curb weights place it within the same weight threshold. In the event that mass reduction causes the vehicle to cross the threshold boundary, equation (43) is applied in two steps, where a portion of the ΔCW reduced (up to the threshold boundary) uses the $Effect_{MY,SC,T}$, $BASE_{SC,T}$, and $FMVSS_{SC,T}$ coefficients from the vehicle's initial weight threshold, and a portion of the ΔCW reduced (beyond the threshold boundary) uses the coefficients from the vehicle's new weight threshold.

The total fatalities attributed to vehicle use and vehicle weight change for vehicles of model year *MY*, belonging to safety class *SC* and weight threshold *T* are, hence, defined as the sum of the two components:

$$F_{MY,SC,T}^{Total} = F_{MY,SC,T} + F_{MY,SC,T}^{\Delta CW} \quad \textbf{(44)}$$

Lastly, total fatalities attributed to all vehicle models produced during model year *MY* are accumulated across all vehicles belonging to safety classes *SC* and weight thresholds *T* as:

$$F_{MY}^{Total} = \sum_{SC,T} F_{MY,SC,T}^{Total} \quad \textbf{(45)}$$

The safety classes, weight thresholds, $Effect_{SC,T}$, $FMVSS_{SC,T}$ and $BASE_{SC,T}$ variables are specified as inputs to the model, which are defined in the parameters input file.

In addition to using inputs to estimate the future involvement of modeled vehicles in crashes involving fatalities, the model also applies inputs defining other accident-related externalities estimated on a dollar per mile basis, as discussed below in S7.7.

Section 7 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 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. Section A.3 of Appendix A provides examples of specific unit economic values and other parameters used to estimate the aggregate value of these various benefits and costs, and explains how these sample values were derived.

S7.1 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 the higher price points, 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.

S7.2 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.

S7.3 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.

S7.4 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.

S7.5 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.

S7.6 Social Benefits and Costs from Increased Fuel Economy

S7.6.1 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.

S7.6.2 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. 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

[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.

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 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.

S7.6.3 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.

S7.7 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 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 to the increase in the total number of miles driven projected to result from the rebound effect.

In addition to external costs, the modeling system also computes costs associated with the cleanup of fatal crashes, attributed to increases in total miles driven and the application of mass reduction technology.

Appendix A Model Inputs

The CAFE Model utilizes a set of data files used as input to the analysis. All input files are specified in Microsoft® Excel format and are outline in Table 7 below. The user can define and edit all inputs to the system.

Table 7. Input Files

Input File	Contents
Market Data (Manufacturers Worksheet)	Contains an indexed list of manufacturers available during the study period, along with manufacturer's willingness to pay fines and other manufacturer-specific modeling settings.
Market Data (Vehicles Worksheet)	Contains an indexed list of vehicle models available during the study period, along with sales volumes, fuel economy levels, prices, regulatory classification, references to specific engines and transmissions used, and settings related to technology applicability.
Market Data (Engines Worksheet)	Contains an indexed list of engines available during the study period, along with various engine attributes and settings related to technology applicability.
Market Data (Transmissions Worksheet)	Contains an indexed list of transmissions available during the study period, along with various transmission attributes and settings related to technology applicability.
Technologies	Specifies estimates of the availability, cost, and effectiveness of various technologies, specific to various vehicle categories.
Parameters	Provides inputs used to calculate travel demand, fuel consumption, carbon dioxide and criteria pollutant emissions (upstream and downstream), and economic externalities related to highway travel and petroleum consumption. Additionally, the parameters input file contains inputs necessary for performing fleet analysis for the EIS.
Scenarios	Specifies coverage, structure, and stringency of CAFE standards for scenarios to be simulated.

A.1 Market Data File

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

A.1.1 Manufacturers Worksheet

The manufacturers input worksheet contains a list of all manufacturers that produce vehicle models offered for sale during the study period. Each manufacturer has a unique code and is represented by a unique manufacturer name. For each manufacturer, the manufacturer code, name, discount rate, payback periods, and whether the manufacturer prefers to pay CAFE fines must all be specified.

Table 8. Manufacturers Worksheet

Category	Column	Units	Definition/Notes
General	Manufacturer Code	integer	Unique number assigned to each manufacturer.
	Manufacturer Name	text	Name of the manufacturer.
	Prefer Fines	text	Represents whether the manufacturer prefers to pay civil penalties instead of applying non cost-effective technologies. - Y = pay fines instead of applying ineffective technologies - N = apply ineffective technologies instead of paying fines
	Discount Rate	number	Represents the manufacturer specific discount rate, which factors into the effective cost calculation. The discount rates are specified per class and style of a vehicle.
	Payback Period	number	The number of years required for an initial investment to be repaid in the form of future benefits or cost savings. The payback periods are specified per class and style of a vehicle.
	Payback Period (OC)	number	The payback period to use after the manufacturer reached compliance.
Banked Credits (credits)	PC-2010 to PC-2014	credits	Represents the manufacturer's available credits, banked from model years preceding the start of analysis, specified for each regulatory class between model years 2010 and 2014.
	LT-2010 to LT-2014	credits	
	2B3-2010 to 2B3-2014	credits	
FFV Credits (mpg)	PC-2015 to PC-2019	mpg	Represents the manufacturer's available FFV credits towards CAFE compliance, specified for each regulatory class between model years 2015 and 2019.
	LT-2015 to LT-2019	mpg	
	2B3-2015 to 2B3-2019	mpg	
ZEV Credits	CA+S177 Sales (%)	zevs	The percentage of manufacturer's total fleet assumed to be sold in California and S177 states.
	CA+S177 ZEV (%)	zevs	The percentage of manufacturer's ZEV credits assumed to be generated in California and S177 states.

A.1.2 Vehicles Worksheet

The vehicles worksheet contains information regarding each vehicle model offered for sale during the study period. Each vehicle model is represented as a single row of input data. Data in Table 9 lists the different columns of information specified in the vehicle models worksheet.

Table 9. Vehicles Worksheet

Category	Column	Units	Definition/Notes
General	Vehicle Code	integer	Unique number assigned to each vehicle.
	Manufacturer	text	The manufacturer of the vehicle.
	Brand	text	The brand name of the vehicle.
	Model	text	Name of the vehicle model.
	Nameplate	text	The nameplate of the vehicle.
	Platform	text	The platform of the vehicle.
	Engine Code	integer	The engine code of the engine that the vehicle uses.
	Transmission Code	integer	The transmission code of the transmission that the vehicle uses.
Fuel Economy	Primary Fuel Type[21]	text	The primary fuel type on which the vehicle operates.
	Primary Fuel Economy[21]	number	The CAFE fuel economy rating of the vehicle on the primary fuel type.
	Secondary Fuel Type[21]	text	The secondary fuel type on which the vehicle operates (if applicable).
	Secondary Fuel Economy[21]	number	The CAFE fuel economy rating of the vehicle on the secondary fuel type (if applicable).
	Fuel Economy (by Fuel Type[22])	number	The CAFE fuel economy rating of the vehicle for each fuel type.
	Fuel Share (by Fuel Type[22])	number	The percent share that the vehicle runs on each fuel type. This value indicates the amount of miles driven by the vehicle on each fuel type. The sum of all fuel shares for any given vehicle must add up to one.
Sales	MY2015	units	Vehicle's projected production for sale in the US.
	MY2016	units	
	…		
	MY2031	units	
	MY2032	units	
MSRP	MSRP	dollars	Vehicle's projected average MSRP (sales-weighted, including options).
Vehicle Information	Origin	text	D = domestic; I = imported
	Style	text	Vehicle style.
	Structure	text	Vehicle structure (ladder or unibody).
	Drive	text	Vehicle drive (A=all-wheel drive, F=front-wheel drive, R=rear-wheel drive, 4=four-wheel drive).
	Wheelbase	inches	The distance between the centers of the front and rear wheels, per SAE J1100, L101 (Sept. 2005).
	Track Width (Front)	inches	The distance between the front left and right wheels, per SAE J1100, W101-1 (Sept. 2005).
	Track Width (Rear)	inches	The distance between the rear left and right wheels, per SAE J1100, W101-2 (Sept. 2005).
	Footprint	sq. feet	The vehicle footprint; wheelbase times average track width.
	Curb Weight	pounds	Total weight of the vehicle, including batteries, lubricants, and other expendable supplies, but excluding the driver, passengers, and other payloads (SAE J1100).
	GVWR	pounds	Gross Vehicle Weight Rating; weight of loaded vehicle, including passengers and cargo.
	GCWR	pounds	Gross Combined Weight Rating; weight of loaded vehicle, including passengers and cargo, as well as the mass of the trailer and cargo in the trailer.
	Max GVWR/CW	proportion	Maximum ratio of GVWR to Curb Weight allowed for the vehicle. During application of mass reduction technology, vehicle's GVWR will be adjusted such that its GVWR/CW ratio does not exceed this value.
	Max GCWR/GVWR	proportion	Maximum ratio of GCWR to GVWR allowed for the vehicle. During application of mass reduction technology, vehicle's GVWR will be adjusted such that its GVWR/CW ratio does not exceed this value.
	Fuel Capacity	gallons	The capacity of the vehicle's fuel tank in gallons of diesel fuel or gasoline; MJ (LHV) of other fuels (or chemical battery energy).
	Employment Hours per Vehicle	hours	Employment hours associated with the production of each vehicle model.

[21] The "Primary Fuel Type", "Primary Fuel Economy", "Secondary Fuel Type", and "Secondary Fuel Economy" columns are specified for reference and are not used by the modeling system. Instead, the values in these columns are used to inform the fuel economies and fuel shares by fuel type specified in adjacent columns.

[22] For each vehicle, fuel economies and fuel shares are reported independently for each of the following fuel types: gasoline, E85, diesel, electricity, hydrogen, and CNG. If the vehicle does not use a specific fuel type, the associated fuel economy and fuel share values will be zero.

<table>
<tr><td rowspan="4">Vehicle Powertrain</td><td>Vehicle Power</td><td>hp</td><td>Maximum horsepower produced by the vehicle's engine or motor.</td></tr>
<tr><td>Vehicle Power (RPM)</td><td>rpm</td><td>The RPM at which vehicle's maximum horsepower is attained.</td></tr>
<tr><td>Vehicle Torque</td><td>lb-ft</td><td>Maximum torque produced by the vehicle's engine or motor.</td></tr>
<tr><td>Vehicle Torque (RPM)</td><td>rpm</td><td>The RPM at which vehicle's maximum torque is attained.</td></tr>
<tr><td rowspan="4">Hybridization</td><td>Type of Hybrid/Electric Vehicle</td><td>text</td><td>Hybridization type of the vehicle, if any.
- 12VSS/SS12V = 12V micro hybrid
- BISG = belt mounted integrated starter generator
- CISG = crank mounted integrated starter generator
- SHEVPS = power-split strong hybrid
- SHEVP2 = P2 strong hybrid
- PHEV = plug-in hybrid
- EV/BEV = battery electric vehicle
- FCV = fuel cell vehicle</td></tr>
<tr><td>Electric Range</td><td>number</td><td>The range of an electric vehicle, in miles, when operating on a battery.</td></tr>
<tr><td>Voltage or Pressure</td><td>volts or psi</td><td>Voltage for HEV/PHEV/EV, pressure for hydraulic hybrid.</td></tr>
<tr><td>Battery Type</td><td>text</td><td>Vehicle's battery type.
- NiMH = Nickel Metal Hydride
- Li-ion = Lithium Ion</td></tr>
<tr><td rowspan="2">Refresh/ Redesign</td><td>Refresh Years</td><td>model year</td><td>List of previous and future refresh years of the vehicle, separated by a semicolon.</td></tr>
<tr><td>Redesign Year</td><td>model year</td><td>List of previous and future redesign years of the vehicle, separated by a semicolon.</td></tr>
<tr><td rowspan="5">Regulatory Classification</td><td>Regulatory Class</td><td>text</td><td>The regulatory assignment of the vehicle.
- PC = the vehicle should be regulated as a passenger automobile
- LT = the vehicle should be regulated as a light truck
- LT2b3 = the vehicle should be regulated as a class 2b/3 truck</td></tr>
<tr><td>Technology Class</td><td>text</td><td>The technology class assignment of the vehicle.</td></tr>
<tr><td>Engine Technology Class</td><td>text</td><td>The engine technology class assignment of the vehicle.</td></tr>
<tr><td>Safety Class</td><td>text</td><td>The safety class assignment of the vehicle.
- PC = the vehicle belongs to a passenger automobile safety class
- LT = the vehicle belongs to a light truck/SUV safety class
- CM = the vehicle belongs to a light CUV/minivan safety class</td></tr>
<tr><td>ZEV Candidate</td><td>text</td><td>Indicates whether a vehicle is a preferred candiate for ZEV technology application. The modeling system will attempt to upgrade ZEV candidates to a PHEV or a BEV in order to meet the ZEV requirement.</td></tr>
<tr><td rowspan="23">Technology Information</td><td>EPS</td><td>text</td><td rowspan="23"><blank> = the technology is not used on the vehicle
USED = the technology is used on the vehicle
SKIP = the technology is not applicable to the vehicle</td></tr>
<tr><td>IACC1</td><td>text</td></tr>
<tr><td>IACC2</td><td>text</td></tr>
<tr><td>SS12V</td><td>text</td></tr>
<tr><td>BISG</td><td>text</td></tr>
<tr><td>CISG</td><td>text</td></tr>
<tr><td>SHEVP2</td><td>text</td></tr>
<tr><td>SHEVPS</td><td>text</td></tr>
<tr><td>PHEV30</td><td>text</td></tr>
<tr><td>PHEV50</td><td>text</td></tr>
<tr><td>BEV200</td><td>text</td></tr>
<tr><td>FCV</td><td>text</td></tr>
<tr><td>LDB</td><td>text</td></tr>
<tr><td>SAX</td><td>text</td></tr>
<tr><td>ROLL10</td><td>text</td></tr>
<tr><td>ROLL20</td><td>text</td></tr>
<tr><td>MR1</td><td>text</td></tr>
<tr><td>MR2</td><td>text</td></tr>
<tr><td>MR3</td><td>text</td></tr>
<tr><td>MR4</td><td>text</td></tr>
<tr><td>MR5</td><td>text</td></tr>
<tr><td>AERO10</td><td>text</td></tr>
<tr><td>AERO20</td><td>text</td></tr>
</table>

The applicability of technologies considered on a vehicle model basis (as opposed, for example, on an engine basis) can be controlled for each vehicle model by using the *Technology*

Information category. Since the modeling system relies heavily on these settings when determining the initial usage and availability of technology to a vehicle, this section must be complete and accurate in order to avoid modeling errors.

A.1.3 Engines Worksheet

Similar to the vehicles input sheet, the engines worksheet contains a list of all engines used in vehicle models offered for sale during the study period. For each manufacturer, the engine code is a unique number assigned to each such engine. This code is referenced in the engine code field on the vehicles worksheet. As in the vehicles worksheet, the *Technology Information* for any engine technology must be complete and accurate for any specific engine.

Table 10. Engines Worksheet

Category	Column	Units	Definition/Notes
General	Engine Code	integer	Unique number assigned to each engine.
	Manufacturer	text	The manufacturer of the engine.
	Configuration	text	Configuration of the engine.
	Fuel	text	One or more fuel types with which the engine is compatible. - G = gasoline - D = diesel - G+E85 = flex fuel engine, running on gasoline and E85 - CNG = compressed natural gas
	Engine Oil Viscosity	text	Ratio between the applied shear stress and the rate of shear, which measures the resistance of flow of the engine oil (as per SAE Glossary of Automotive Terms).
	Cycle	text	Combustion cycle of the engine.
	Air/Fuel Ratio	number	Weighted (FTP+highway) air/fuel ratio (mass).
	Fuel Delivery System	text	The mechanism that delivers fuel to the engine.
	Aspiration	text	Breathing or induction process of the engine (per SAE Glossary of Automotive Terms). - NA = naturally aspirated - S = supercharged - T = turbocharged - T2 = twin-turbocharged - T4 = quad-turbocharged - ST = supercharged and turbocharged
	Valvetrain Design	text	Design of the total mechanism from camshaft to valve of an engine that actuates the lifting and closing of a valve (per SAE Glossary of Automotive Terms).
	Valve Actuation/Timing	text	Valve opening and closing points in the operating cycle (SAE J604). - F = fixed - VVT = variable valve timing - ICP = intake cam phasing VVT - DCP = dual cam phasing VVT - CCP = coupled cam phasing VVT
	Valve Lift	text	The manner in which the valve is raised during combustion (per SAE Glossary of Automotive Terms). - F = fixed - VVL = variable valve lift - DVVL = discrete VVL - CVVL = continuous VVL
	Cylinders	integer	Number of engine cylinders.
	Valves/Cylinder	integer	Number of valves per cylinder.
	Deactivation	text	Indicates whether the engine includes a cylinder deactivation mechanism. - Y = cylinder deactivation applied - N = cylinder deactivation not applied
	Displacement	liters	Total volume displaced by a piston in a single stroke.
	Compression Ratio (Min)	number	Minimum compression ratio of an engine.
	Compression Ratio (Max)	number	Maximum compression ratio of an engine.
Classifications	Engine Size	text	The relative size of the engine, with respect to technology application. Allowed values are: - SD or Small = a small sized engine - MD or Medium = a medium sized engine - LD or Large = a large sized engine

Technology Applicability	SOHC	text	<blank> = the technology is not used on the engine USED = the technology is used on the engine SKIP = the technology is not applicable to the engine
	DOHC	text	
	OHV	text	
	TEFRI	text	
	LUBEFR1	text	
	LUBEFR2	text	
	LUBEFR3	text	
	VVT	text	
	VVL	text	
	SGDI	text	
	DEAC	text	
	HCR	text	
	TURBO1	text	
	SEGR	text	
	DWSP	text	
	TURBO2	text	
	CEGR1	text	
	CEGR2	text	
	LGDI	text	
	CNG	text	
	ADSL	text	
	TURBODSL	text	
	IPIDSL	text	
	DWSPDSL	text	
	EFRDSL	text	
	CLCDSL	text	
	LPEGRDSL	text	
	DSIZEDSL	text	

A.1.4 Transmissions Worksheet

Similar to the vehicles and engines input sheets, the transmissions worksheet contains a list of all transmissions used in vehicle models offered for sale during the study period. For each manufacturer, the transmission code is a unique number assigned to each such transmission. This code is referenced in the transmission code field on the vehicles worksheet. As in the vehicles worksheet, the the transmission code field on the vehicles worksheet *Technology Information* for any transmission technology must be complete and accurate for any specific transmission.

Table 11. Transmissions Worksheet

Category	Column	Units	Definition/Notes
General	Transmission Code	integer	Unique number assigned to each transmission.
	Manufacturer	text	The manufacturer of the transmission.
	Type	text	Type of the transmission. - M = manual - A = automatic (torque converter) - AMT = automated manual transmission (single clutch w/ torque interrupt) - DCT = dual clutch transmission - CVT = belt or chain CVT
	Number of Forward Gears	integer	Number of forward gears the transmission has.
Technology Applicability	MT5	text	<blank> = the technology is not used on the transmission USED = the technology is used on the transmission SKIP = the technology is not applicable to the transmission
	MT6	text	
	MT7	text	
	TATI	text	
	AT5	text	
	ATI1	text	
	ATI2	text	
	AT6	text	
	AT8	text	
	CVT	text	
	DCT6	text	
	DCT8	text	

A.2 Technologies File

The technologies input file contains assumptions regarding the fuel consumption benefit, cost, and applicability of different vehicle, platform, engine, and transmission-level technologies available during the study period. As described in Section S2.2.1 above, input assumptions are defined for the seven vehicle technology classes listed in Table 3 and sixteen engine technology classes listed in Table 4. Input assumptions that are common among all technology classes are listed on a separate technologies definitions tab. Table 12 shows the contents of a technologies definitions tab for all classes while Table 13 and Table 14 shows the contents of the technology assumptions tabs.

Table 12. Technology Definitions

Category	Column	Units	Definition/Notes
General	Index	integer	Unique index assigned to each technology.
	Name	text	Name of the technology.
	Technology Description	text	Description of the technology.
	Technology Path	text	The path within which the technology progresses. For most technologies, the incremental costs and fuel consumption improvements are accrued over the preceding technology within the same path.
	Phase-in Cap	percentage	Percentage of the entire fleet to which the technology may be applied.
Off-Cycle Credits	PC OCC	grams per mile	Amount of off-cycle credit that the vehicles incur as a result of applying the technology. Specified in grams per mile of CO2 for each regulatory class.
	LT OCC		
	2b3 OCC		
Other	ZEV Credits	zevs	Amount of ZEV credits a vehicle will generate upon application of the technology.

The technology assumptions inputs listed in Table 13 are specified for each technology and for each of the defined vehicle technology class.

Table 13. Technology Assumptions

Category	Column	Units	Definition/Notes
General	Index	integer	Unique index assigned to each technology.
	Name	text	Name of the technology.
	Technology Path	text	The path within which the technology progresses.
Availability	Applicable	boolean	TRUE = the technology is available for applicability in a technology class FALSE = the technology is not available for applicability in a technology class
	Year Avail.	model year	First year the technology is available for applicability.
	Year Retired	model year	Last year the technology is available for applicability.
FC Improvements	FC	percentage	Fuel consumption improvement estimate of a technology.
	Secondary FC	percentage	Fuel consumption improvement estimate of a technology, when a vehicle is operating on its secondary fuel type (applicable when a vehicle is being converted into a plug-in HEV or another form of dual fuel vehicle).
	Secondary FS	percentage	Percentage of miles a vehicle is expected to travel on its secondary fuel after applying a dual-fuel technology (applicable when a vehicle is being converted into a plug-in HEV or another form of dual fuel vehicle).
Misc Attributes	Electric Range	number	Indicates what the range, in miles, of an electric vehicle would be when operating on a battery, as a result of applying the technology (applies to PHEV and EV technologies only).
	Electric Power	hp	Indicates what the power of an electric vehicle would be when operating on a battery, as a result of applying the technology (applies to PHEV and EV technologies only).
	Delta Weight (%)	percentage	Percentage by which the vehicle's weight changes as a result of applying the technology.
	Delta Weight (lbs)	number	Amount of pounds by which the vehicle's weight changes as a result of applying the technology.
	Consumer Valuation	dollars	The consumer welfare loss (or gain) associated with application of the technology.

The technology costs inputs shown in Table 14 are specified for each technology, for each of the defined vehicle technology classes as well as each of the defined engine technology classes.

Table 14. Technology Costs

Category	Column	Units	Definition/Notes
General	Index	integer	Unique index assigned to each technology.
	Name	text	Name of the technology.
	Technology Path	text	The path within which the technology progresses.
Cost Table	C2015	dollars	Table of learned out cost estimates for the technology, per model year.
	C2016	dollars	
	…		
	C2031	dollars	
	C2032	dollars	
Maint. Table	M2015	dollars	Table of learned out maintenance cost estimates for the technology, per model year.
	M2016	dollars	
	…		
	M2031	dollars	
	M2032	dollars	
Repair Table	R2015	dollars	Table of learned out repair cost estimates for the technology, per model year.
	R2016	dollars	
	…		
	R2031	dollars	
	R2032	dollars	
Stranded Capital Table	SC-1	dollars	Penalty costs associated with replacing (or superseding) a technology early.
	SC-2	dollars	
	…		
	SC-9	dollars	
	SC-10	dollars	

A.2.1 Technology Synergies

The technologies input file contains two additional worksheets for specifying fuel consumption adjustments (or synergies) and cost adjustments to augment the base improvement factor and cost of a technology. The detailed description and applicability of the synergy values are described in Sections S2.2.5 and S2.2.6 above. Table 15 shows the contents of the technology synergies worksheets.

Table 15. Technology Synergies

Category	Column	Units	Definition/Notes
General	Technologies	text	Combination of technologies to which the fuel consumption adjustment or cost synergy applies.
Adjustment Factors by Class	SmallCar	number	Fuel consumption multiplier by which to adjust a vehicle's fuel economy whenever application of a technology results in a vehicle's "technology utlization state" being equal to a combination specified in the "technologies" column. A separate adjustment factor is specified for each technology class.
	MedCar		
	SmallSUV		
	MedSUV		
	Pickup		
	Truck2b3		
	Van2b3		
Adjustment Factors by Cost Class	2C1B	dollars	The amount by which to offset the technology cost whenever application of a technology results in a vehicle using all technologies specified in the "technologies" column. A separate synergy value is specified for each technology cost class.
	3C1B		
	4C1B		
	4C2B		
	5C1B		
	6C1B		
	6C1B_OHV		
	6C2B		
	6C2B_OHV		
	8C2B		
	8C2B_OHV		
	10C2B		
	10C2B_OHV		
	12C2B		
	12C4B		
	16C4B		
	NA		

A.3 Parameters File

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

A.3.1 Vehicle Age Data

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

Table 16. Vehicle Age Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Vehicle Age Data	Survival Rates	proportion	Proportion of original vehicle sales that remain in service by vehicle age (year 1 to 30 for cars, 1 to 37 for trucks).
	Miles Driven	miles	Average annual miles driven by surviving vehicles by vehicle age (year 1 to 30 for cars, 1 to 37 for trucks).

Separate survival fractions and annual miles driven are used for cars, vans, SUVs, pickups, ZEVs, and class 2b/3 trucks. The survival fractions measure the proportion of vehicles originally produced during a model year that remain in service at each age, by which time only a small fraction typically remain in service.

A.3.2 Fuel Prices

The Fuel Prices worksheet contains historic and estimates of future fuel prices, which are used when calculating pre-tax fuel outlays and fuel tax revenues.

Table 17. Forecast Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fuel Prices	Retail Fuel Prices (low, average, high)	$/gallon	2013 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-1975.
	Fuel Taxes	$/gallon	2013 $ per gallon, varies by fuel type, forecast by calendar year staring with MY-2000.

A.3.3 Fuel Economy Data

The Fuel Economy Data worksheet contains historic and projected fuel economy levels for passenger cars, light trucks, and class 2b/3 trucks, for each fuel type (gasoline, diesel, ethanol-85, electricity, and hydrogen). The associated fuel shares are also provided.

Table 18. Fuel Economy Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fuel Economy Data	Fuel Economy (by Fuel Type and Fleet)	mpg	Historic and projected fuel economy levels for each available fuel type and fleet type.
	Fuel Share (by Fuel Type and Fleet)	percentage	Historic and projected fuel shares for each available fuel type and fleet type.

A.3.4 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 the economic values in Table 19 were obtained from various sources of information, the system does not require that the user rely on these sources.

Table 19. Economic Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Economic Values	Rebound Effect	percentage	Increase in the annual use of vehicle models in response to lower per-mile cost of driving a more fuel-efficient vehicle.
	Discount Rate	percentage	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; used for calculating socially valued benefits.
	Base Year for Discounting	percentage	The calendar year to use for "present year" discounting. If a base year value is used, social discounting is assumed, with all costs and benefits being discounted to that year. If no value is specified, private discounting is implied, with all costs and benefits being discounted to the model year being analyzed.
	Annual Growth Rate for Average VMT per Vehicle	***various***	Annual growth rate for average VMT per vehicle.
	Base Year for Average Annual Usage Data	model year	Base year for annual growth rate for average VMT per vehicle.
	Growth Rate at Low Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using low fuel prices.
	Growth Rate at Average Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using average fuel prices.
	Growth Rate at High Fuel Price	percentage	Annual growth rate for average VMT per vehicle, when using high fuel prices.
	"Gap" between Test and On-Road MPG (by Fuel Type)	percentage	Difference between a vehicle's EPA fuel economy rating and its actual on-road fuel economy.
	Fixed Component of Average Refueling Time in Minutes (by Fuel Type)	minutes	Average refueling time a spent by a consumer refueling the vehicle tank or recharging the vehicle electric battery.
	Average Tank Volume Refueled	percentage	Average tank volume refilled during a refueling stop.
	Value of Travel Time per Vehicle	$/hour	Amount that the driver of a vehicle would be willing to pay to reduce the time required to make a trip.
	External Costs from Additional Vehicle Use Due to "Rebound" Effect	***$/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.
	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.
	Ownership and Operating Costs		
	Taxes & Fees (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer pays in taxes and fees when purchasing a new vehicle.
	Financing (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer would pay for financing a new vehicle.
	Insurance (% of final vehicle MSRP)	percentage	Average percentage of the vehicle's final MSRP the consumer would pay for insuring a new vehicle.
	Relative Value Loss (% of final vehicle MSRP, pure EVs only)	percentage	Average percentage of the vehicle's final MSRP, which translates into relative value loss to consumer due to decreased operating life of pure electric vehicles.
	Resale Value	percentage	Average percentage of the vehicle's final MSRP the consumer recoups after selling the vehicle.
	Economic Costs of 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.
	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.

A.3.5 Fleet Analysis Values

The Fleet Analysis Values worksheet contains fine tuning parameters for performing fleet analysis calculations. The Forecast of Sales contains projected vehicle production for sale in the U.S. between model years 2014 and 2064 and is used to estimate additional car and truck fleet values, beyond what is available on the Historic Fleet Data worksheet (discussed below). When fleet analysis option is used, the system evaluates modeling effects for historic and forecast model years, producing outputs required for the EIS.

Table 20. Fleet Analysis Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fleet Analysis Values	***Fuel Economy Growth Rates***		
	Baseline Scenario (by Fleet Type)	percentage	Growth rates used to estimate additional fuel economy growth beyond the last model year covered during the study period for the baseline scenario.
	Action Alternatives (by Fleet Type)	percentage	Growth rates used to estimate additional fuel economy growth beyond the last model year covered during the study period for the action alternatives.
	CAFE Start Year (by Fleet Type)	model year	The model year when Fuel Economy regulations were first introduced. This value is useful when evaluating the fuel use and environmental effects assuming the absence of CAFE standards. This value is not used in this version of the model.
	Forecast of Sales (by Fleet Type)	units	The forecast of total industry sales by model year. The first model year specified should be immediately following the last model year from the Historic Fleet Data. Forecast of Sales are used to scale individual vehicle sales, after the last compliance model year, in order to evaluate the fuel use and environmental effects of future years during Fleet Analysis.

A.3.6 Historic Fleet Data

The Historic Fleet Data worksheet provides historic data of vehicles remaining on the road, specified by model year for each vehicle age, for the car, class 1/2a truck, and class 2b/3 truck fleets. The period of years covered is between 1975 and 2014.

Table 21. Historic Fleet Data Worksheet

Category	Model Characteristic	Units	Definition/Notes
Historic Fleet Data	Fleet Data (by Fleet Type)	units	Historic car and truck fleet data for each fleet type and model year, specified by vehicle age.

A.3.7 Safety Values

The Safety Values worksheet contains parameters for estimating additional fatalities resulting from decreases in vehicle weight.

Table 22. Safety Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Safety Values	PC Threshold	lbs.	The boundary between small and large weight effects by safety class.
	LT/SUV Threshold	lbs.	
	CUV/Minivan Threshold	lbs.	
	Change per 100 lbs.	percentage	Change per 100 lbs. below the weight threshold.
	Base per billion miles		Base fatalities per billion miles below the weight threshold.
	Adjustment for new FMVSS		Adjustment for new FMVSS below the weight threshold.
	Monetized Fatalities		
	Cost Value	dollar	Social costs arising from vehicle fatalities.
	Growth Rate	percentage	Annual growth rate for fatality costs per vehicle.
	Base Year for Annual Growth	model year	Base year for annual growth rate for fatality costs per vehicle.

A.3.8 Credit Trading Values

The Credit Trading Values worksheet contains fine tuning parameters for enabling credit transfers and credit carry forward within the model.

Table 23. Credit Trading Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
Credit Trading Values	***Credit Trading Options***		Fine Tuning Parameters for using Credit Trading option in the model.
	Trade credits between manufacturers	boolean	Whether to allow credit trading between manufacturers within the same compliance category (i.e., regulatory class) and model year. This option is not supported in this version of the model.
	Transfers credits between regulatory classes	boolean	Whether to allow credit transfers between regulatory class within the same manufacturer and model year.
	Carry credits forward into future model years	boolean	Whether to allow carrying of credits forward into the analysis year from earlier model years within the same manufacturer and compliance category.
	Maximum number of years to carry forward	integer	Maximum number of model years to look forward.
	Carry credits backward into past model years	boolean	Whether to allow carrying of credits backward into the analysis year from future model years within the same manufacturer and compliance category. This option is not supported in this version of the model.
	Maximum number of years to carry backward	integer	Maximum number of model years to look backward. This option is not supported in this version of the model.
	Transfer Caps (mpg)	mpg	Transfer caps corresponding to the maximum amount of credits that may be transferred into a compliance category for each model year. The cap from the latest model year is carried forward for all subsequent years.
	Assumed Lifetime VMT by Regulatory Class	miles	Assumed lifetime VMT to use when credits are transferred between compliance categories.
	Additional Runtime Options		
	Maximum Expiring Credit Years to Consider	integer	The modeling system will attempt to use available credits before they expire. This setting indicates maximum number of model years to consider when using expiring credits.

A.3.9 ZEV Credit Values

The ZEV Credit Values worksheet contains parameters allowing the modeling system to target the ZEV requirements of CA+S177 states during compliance simulation.

Table 24. ZEV Credit Values Worksheet

Category	Model Characteristic	Units	Definition/Notes
ZEV Credit Values	ZEV Requirement (%)	percentage	Minimum percentage of zero emission vehicle (ZEV) credits that a manufacturer must generate in order to meet the ZEV requirement in each specified model year.
	Max Credits from PHEV (%)	percentage	Maximum percentage of ZEV credits that a manufacturer may generate from PHEVs in order to meet the ZEV requirement in each specified model year.

The DFS Model Values worksheet contains fine tuning parameters for utilizing the Dynamic Fleet Share model within the modeling system. When enabled, the DFS model adjusts the production volumes in future model years as a response to increasing fuel economies and costs of vehicle models within a given compliance category.

Category	Model Characteristic	Units	Definition/Notes
DFS Model Values	Initial Share of the LDV fleet (passenger cars)	percentage	Indicates the fleet share of the LDV fleet, versus the entire light duty fleet (cars and trucks), for the model year immediately preceding the first analysis year.
	Initial Fuel Economy of the LDV fleet (passenger cars)	mpg	Average fuel economy for the LDV fleet for the model year immediately preceding the first analysis year.
	Initial Fuel Economy of the LDT1/2a fleet (trucks, class 1/2a)	mpg	Average fuel economy for the LDT1/2a fleet for the model year immediately preceding the first analysis year.
	Initial Fuel Economy of the LDT2b/3 fleet (trucks, class 2b/3)	mpg	This option is not supported in this version of the model.
	Epsilon ("randomizer" parameter)	number	Additional constant that serves as a "randomizer" when dynamically adjusting the PC/LT fleet share. This value should typically be zero.

A.3.10Fuel 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 25. Fuel Properties Worksheet

Category	Model Characteristic	Units	Definition/Notes
Fuel Properties	Share of Total Assumed Fuel Mix	percentage	Estimated share of total fuel consumption by fuel type.
	Energy Density	BTU/unit	Amount of energy stored in a given system or region of space per unit volume, specified by fuel type.
	Mass Density	grams/unit	Mass per unit volume, specified by fuel type.
	Carbon Content	percentage by weight	Average share of carbon in fuel, specified by fuel type.
	SO-2 Emissions	grams/unit	Sulfur Oxides emissions rate of gasoline and diesel fuels.
	Fuel Import Assumptions		
	Share of Fuel Savings Leading to Lower Fuel Imports	percentage	Assumed value for share of fuel savings leading to lower fuel imports.
	Share of Fuel Savings Leading to Reduced Domestic Fuel Refining	percentage	Assumed value for share of fuel savings leading to reduced domestic fuel refining.
	Share of Reduced Domestic Refining from Domestic Crude	percentage	Assumed value for share of reduced domestic refining from domestic crude.
	Share of Reduced Domestic Refining from Imported Crude	percentage	Assumed value for share of reduced domestic refining from imported crude.

The Emission Costs Worksheet contains emission damage costs arising from various pollutants.

Table 26. Emission Costs Worksheet

Category	Model Characteristic	Units	Definition/Notes
Emission Costs	***Emission Damage Costs***		
	Carbon Monoxide	$/metric-ton	Economic costs arising from Carbon Monoxide damage.
	Volatile Organic Compounds	$/metric-ton	Economic costs arising from Volatile Organic Compounds damage.
	Nitrogen Oxides	$/metric-ton	Economic costs arising from Nitrous Oxides damage.
	Particulate Matter	$/metric-ton	Economic costs arising from Particulate Matter damage.
	Sulfur Dioxide	$/metric-ton	Economic costs arising from Sulfur Oxides damage.
	Methane	scalar	Economic costs arising from Methane damage, specified as GWP-scalar of CO-2 Costs.
	Nitrous Oxide	scalar	Economic costs arising from Nitrous Oxide damage, specified as GWP-scalar of CO-2 Costs.
	CO-2 Damage		
	CO-2 Discount Rates	percentage	Discount rates to apply to low, average, high, or very high Carbon Dioxide estimates.
	Cost of CO-2	$/metric ton	Economic costs arising from Carbon Dioxide damage, by calendar year; estimates for low, average, high, or very high growth rates are provided.

A.3.11 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 27. Upstream Emissions Worksheet

Category	Model Characteristic	Units	Definition/Notes
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.
	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.
	Subtotals	grams/mil BTU	Subtotals from all stages of fuel production and distribution.

A.3.12Tailpipe Emissions

With this revision of the modeling system, the tailpipe emission inputs were condensed into two input sheets: the TE_Gasoline and TE_Diesel, specifying emissions from gasoline and diesel operation, respectively. These worksheets contain vehicular criteria pollutant emission factors specified by vehicle age and vehicle class (LDV, LDT1/2a, and LDT2b/3), with each group of columns representing a different pollutant. For simplicity, gasoline and e85 fuels utilize the tailpipe emissions provided on the TE_Gasoline worksheet, diesel fuel uses the emissions specified on the TE_Diesel worksheet, while the remainder of the fuel types (*e.g.*, electricity) are assumed not to generate any tailpipe emissions.

Table 28. Tailpipe Emissions Worksheets

Category	Model Characteristic	Units	Definition/Notes
TE_Gasoline & TE_Diesel	Emission Rates (by Fuel Type and Fleet)	grams/mile	Vehicle emission rates from gasoline operation. Emission rates are specified for each fleet (LDV, LDT1/2a, and LDT2b/3), for historic and future model years, and for each vehicle age.

A.4 Scenarios File

The scenarios file provides one or more worksheets that begin with "SCEN_" and are identified as CAFE program scenarios, which are defined in terms of the design and stringency of the CAFE program. The system numbers these scenarios as 0, 1, 2 …, based on their order of appearance. The first worksheet is assigned to Scenario 0, and is identified as the baseline scenario to which all others are compared. Each scenario defines the CAFE program as it relates to the following "regulatory classes":

Table 29. Regulatory Classes

Reg. Class	Includes
Passenger Car	All passenger automobiles
Light Truck	Class 1 and class 2a trucks
Light Truck 2b/3	Class 2b and class 3 trucks

The "Regulatory Class" column on the vehicles worksheet discussed above is used to indicate whether the vehicle is regulated as a Passenger Car (PC), Light Truck (LT), or Light Truck 2b/3 (2b3).

Within each scenario worksheet, the specifications for each regulatory class are defined separately, using the parameters described in Table 30 below.

\Table 30. Scenarios Worksheet

Category	Column	Units	Definition/Notes
Function Definition	Function	integer	Functional form to use for computing the vehicle target.
	A - J (function coefficients)	number	Coefficients associated with the functional form to use for computing the vehicle target.
	Min (mpg)	mpg	Minimum CAFE standard that each manufacturer must attain, specified as a flat-standard in miles/gallon, or 0 if not applicable.
	Min (%)	percentage	Minimum CAFE standard that each manufacturer must attain, specified as a percentage of the average requirement under the function-based standard, or 0 if not applicable.
Supplemental Options	Allow Fines	boolean	Indicates whether manufacturers are allowed to pay CAFE fines for non-compliance instead of applying additional technologies.
	Fine Rate	number	The CAFE fine rate for non-compliance in dollars per one credit of shortfall.
	Multi-Fuel	integer	The applicability of multi-fuel vehicles for compliance calculations (does not apply to single-fuel vehicles): 0 = only gasoline fuel economy value is considered (gasoline fuel share is assumed to be 100%); 1 = for Gasoline/Ethanol-85 vehicles, only the gasoline fuel economy value is considered (gasoline fuel share is assumed to be 100%); for Gasoline/Electricity vehicles, both fuel economy values are considered; 2 = for Gasoline/Ethanol-85 and Gasoline/Electricity vehicles, both fuel economy values are considered.
	FFV Share	percentage	The statutory fuel share to use for compliance for flex-fuel vehicles (FFVs), whenever the Multi-Fuel mode is 2. This fuel share applies only to vehicles operating on gasoline and ethanol-85 fuel types. If 0 or <blank> is used, the vehicle's assumed on-road fuel share will be used for compliance.
	PHEV Share	percentage	Specifies the statutory fuel share to use for compliance for plug-in hybrid/electric vehicles (PHEVs), whenever the Multi-Fuel mode is either 1 or 2. This fuel share applies only to vehicles operating on gasoline and electricity fuel types. If 0 or <blank> is used, the vehicle's assumed on-road fuel share will be used for compliance.
	Include AC	boolean	Whether to include adjustments for improvements in air conditioning (AC adjustments) for compliance and effects calculations: TRUE = include AC credits for compliance and effects calculations (credits, fines, and whether mfr is in compliance); FALSE = do not include AC credits for compliance and effects calculations (the achieved CAFE in modeling reports will still show "CAFE w/o AC" as well as "CAFE with AC").
	AC Adjustment	number	The AC adjustment factor in grams/mile of CO2.
	AC Cost ($)	dollar	The cost of AC adjustment in dollars per unit.
	Off-Cycle Cap	number	The maximum amount of credit a manufacturer may accrue from Off-Cycle technology improvements, specified in grams/mile of CO2.
	FFV Cap	number	The maximum amount of credit a manufacturer may accrue from flex-fuel vehicles (FFVs), specified in vehcle-miles/gallon. This option is not supported in this version of the model.
	SHEV Tax Credit	dollar	The amount of Federal tax credits a buyer receives for purchasing a strong hybrid/electric vehicle (SHEV).
	PHEV Tax Credit	dollar	The amount of Federal tax credits a buyer receives for purchasing a plug-in hybrid/electric vehicle (PHEV).
	EV Tax Credit	dollar	The amount of Federal tax credits a buyer receives for purchasing a pure electric vehicle (EV).
	TW Function	integer	The functional form to use for computing the vehicle's test weight.
	Payload Return	percentage	The percentage of curb weight reduction returned to payload capacity. This setting applies whenever mass reduction technology is installed to a vehicle. For example, if payload return is 0%, the vehicle's payload capacity remains the same; if payload return is 100%, the vehicle's reduction in curb weight goes entirely to payload.
	Towing Return	percentage	The percentage of GVWR reduction returned to towing capacity. This setting applies whenever mass reduction technology is installed to a vehicle. For example, if towing return is 0%, the vehicle's towing capacity remains the same; if towing return is 100%, the vehicle's reduction in GVWR goes entirely to towing.
	Credit Carry Fwd	integer	The maximum number of years to carry forward. If a value is specified, this setting overrides the value present in the parameters file. If 0 or <blank> is specified, the default value from the parameters file will be used.

Appendix B Model Outputs

The system produces seven output files in comma separated values (CSV) format. The system places all files in the "reports" folder, located in the user selected output path (ex: **C:\cafe\demo-run\demo\reports-csv**). Table 31 lists the available output types and their contents. With the last revision of the modeling system, the structure of all outputs generated has changed from earlier versions. The "raw" modeling results are stored as plain text (without any additional formatting), in a "database-like" style. Most of the modeling reports have been extended to include additional information, while some were scaled down to contain only the relevant portions. As discussed earlier, the first scenario appearing in the scenarios file is assigned to Scenario 0 and is treated as the baseline. The action alternatives are then assigned to Scenario 1, 2, and so on, in order of appearance. For all modeling reports, the baseline scenario always shows absolute values, while, for the majority of reports, the action alternatives include relative changes compared to the baseline, as discussed in the sections below.

Table 31. Output Files

Output File	Contents
Technology Utilization Report	Contains manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Compliance Report	Contains manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
Societal Effects Report	Contains industry-wide summary of energy and emissions effects for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
Societal Costs Report	Contains industry-wide summary of consumer and social costs for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
Annual Societal Effects Report	This output file is similar to the *Societal Effects Report*, except it further disaggregates the results by calendar year.
Annual Societal Costs Report	This output file is similar to the *Societal Costs Report*, except it further disaggregates the results by calendar year.
Vehicles Report	Contains disaggregate vehicle-level summary of compliance model results, providing a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed.

The remainder of this section discusses the contents of the output files.

B.1 Technology Utilization Report

The *Technology Utilization Report* contains manufacturer-level and industry-wide technology application and penetration rates for each technology. The application rates represent the amount of technology that was applied by the modeling system during analysis while the penetration rates represent the amount of technology that was either on the vehicle initially at the start of the analysis, or applied by the modeling system during analysis. If a technology was present on or applied to a vehicle, but later superseded during the modeling process by another technology (for example, AT8 superseding AT6), the superseded technology on that vehicle will not count toward the penetration rate.

Some of the technologies which are present in the baseline fleet, but are not explicitly analyzed by the modeling system also appear in the report. An example of such technology is E85 FFV (ethanol-85 flex-fuel vehicles).

The following table lists the contents of the *Technology Utilization Report*.

Table 32. Technology Utilization Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period.
Manufacturer	text	Manufacturers analyzed during the study period. A value of "TOTAL" is used to represent industry-wide results.
Reg-Class	text	The regulatory class for which the application and penetration rates are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sum across all classes.
Technology (abbreviation)	text	The technology for which the application and penetration rates are reported.
App-Rate	number	The application rate of the technology, specified as a proportion of total sales. The application rates represent the amount of technology that was applied by the modeling system during analysis. If a technology was applied to a vehicle, but later superseded during the modeling process by another technology (for example, AT8 superseding AT6), the superseded technology on that vehicle will not count toward the application rate.
Pen-Rate	number	The penetration rate of the technology, specified as a proportion of total sales. The penetration rates represent the amount of technology that was either on the baseline vehicle at the start of the analysis, or applied by the modeling system during analysis. If a technology was present on or applied to a vehicle, but later superseded during the modeling process by another technology (for example, AT8 superseding AT6), the superseded technology on that vehicle will not count toward the penetration rate.
Incr.AR	number	The incremental application rate of the technology, which represents the difference between the action alternative and the baseline scenario.
Incr.PR	number	The incremental penetration rate of the technology, which represents the difference between the action alternative and the baseline scenario.

B.2 Compliance Report

The *Compliance Report* contains manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are reported by regulatory class, as well as aggregated for the entire fleet. Most of the metrics, which are reported independently by model year, are further summed (or averaged) over the entire analysis period. The report provides various cost values associated with the rule, represented as "totals" across all vehicle models, as well as "averages" per single vehicle unit. The following table lists the contents of the *Compliance Report*.

Table 33. Compliance Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "TOTAL" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Manufacturer	text	Manufacturers analyzed during the study period. A value of "TOTAL" is used to represent industry-wide results.
Reg-Class	text	The regulatory class for which the compliance results are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Sales	units	Total production of vehicles for sale for a specific model year, manufacturer, and regulatory class (as well as sum across any of the attributes, where applicable).
k.Labor Hours	hours (k)	Thousands of employment hours associated with the production of vehicle models. (The modeling system applies any employment hours specified in the input file; however, the system reflects no predetermined assumptions regarding the context for these inputs.)
Prelim-Stnd	mpg	Preliminary value of the required CAFE standard (before the "alternative minimum CAFE standard", as outlined in the scenarios input section, is applied).
Standard	mpg	The value of the required CAFE standard.
CAFE (2-cycle)	mpg	The value of the achieved CAFE standard, using a 2-bag test cycle, not including the adjustment for improvements in air conditioning or off-cycle credits.
CAFE	mpg	The value of the achieved CAFE standard, including the adjustment for improvements in air conditioning and off-cycle credits. This value is used for compliance purposes.
Average CW	lbs.	Average curb weight of analyzed vehicles.
Average FP	sq.ft.	Average footprint of analyzed vehicles.
Average WF	lbs.	Average work-factor of analyzed vehicles. This value is reported only when the vehicles analyzed are subject to the work-factor based functional standards.
CO2 Required	grams per mile	The value of the required CO-2 standard.
CO2 Achieved	grams per mile	The value of the achieved CO-2 standard.
ZEV Target	zevs	Amount of ZEV credits required in order to meet the CA+S177 state's zero-emission vehicle standards.
ZEV Credits	zevs	Amount of ZEV credits generated for compliance with the CA+S177 state's zero-emission vehicle standards.
Tech Cost	dollars[1]	Total amount of technology costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class.
Fines	dollars[1]	Total amount of fines paid by a manufacturer for a specific model year and regulatory class.
Reg-Cost	dollars[1]	Total amount of regulatory costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class. The regulatory costs are the sum of technology costs and fines.
Disc Cost	dollars[1]	Total amount of technology costs accrued by all vehicles for a specific model year, manufacturer, and regulatory class. If social discounting is used, the technology costs are discounted to the "Base Year for Discounting" value specified in the parameters file. If private discounting is used, the discounted costs are the same as technology costs.
Value Loss	dollars[1]	Total loss in value to the consumer due to decreased range of pure electric vehicles.
Rel. Value Loss	dollars[1]	Total relative loss in value to the consumer due to due to decreased operating life of pure electric vehicles.
Maint Cost	dollars[1]	Total maintenance costs accrued due to application of additional technologies.
Repair Cost	dollars[1]	Total repair costs accrued due to application of additional technologies.
Taxes/Fees	dollars[1]	Total amount of taxes & fees paid by the consumers for purchasing new vehicles for a specific model year, manufacturer, and regulatory class.
Financing	dollars[1]	Total amount paid by the consumers for financing new vehicles for a specific model year, manufacturer, and regulatory class.

Insurance	dollars[1]	Total amount paid by the consumers for insuring new vehicles for a specific model year, manufacturer, and regulatory class.
Total Consumer Costs	dollars[1]	The total consumer costs accumulated by the manufacturer for a specific model year and regulatory class. The consumer costs are the sum of: discounted technology costs, fines, taxes & fees, financing costs, insurance costs, maintenance costs, repair costs, loss of value, and relative loss of value.
Total Social Costs	dollars[1]	The total social costs accumulated by the manufacturer for a specific model year and regulatory class. The social costs are the sum of: discounted technology costs, maintenance costs, repair costs, loss of value, and relative loss of value.
Avg Tech Cost	dollars[1]	Average technology costs per single vehicle unit.
Avg Fines	dollars[1]	Average fines paid per single vehicle unit.
Avg Reg-Cost	dollars[1]	Average regulatory costs per single vehicle unit.
Avg Disc Cost	dollars[1]	Average technology costs per single vehicle unit. If social discounting is used, the technology costs are discounted to the "Base Year for Discounting" value specified in the parameters file. If private discounting is used, the average discounted costs are the same as average technology costs.
Avg Value Loss	dollars[1]	Average loss in value per single vehicle unit.
Avg Rel. Value Loss	dollars[1]	Average relative loss in value per single vehicle unit.
Avg Maint Cost	dollars[1]	Average maintenance costs per single vehicle unit.
Avg Repair Cost	dollars[1]	Average repair costs per single vehicle unit.
Avg Taxes/Fees	dollars[1]	Average taxes & fees per single vehicle unit.
Avg Financing	dollars[1]	Average financing costs per single vehicle unit.
Avg Insurance	dollars[1]	Average insurance costs per single vehicle unit.
Avg Consumer Costs	dollars[1]	Average consumer costs per single vehicle unit.
Avg Social Costs	dollars[1]	Average social costs per single vehicle unit.
Credits Earned	credits[2]	Total credits accumulated by the manufacturer for a specific model year and regulatory class. Manufacturers earn compliance credits whenever their achieved value of the CAFE standard is above the required value of the CAFE standard (in mpg).
Credits Out	credits[2]	Total credits transferred out of a specific regulatory class (such as from domestic passenger automobiles to light trucks) or carried forward from a previous model year.
Credits In	credits[2]	Total credits transferred into a specific regulatory class or carried forward into the present model year.

In the above table, note that:

(1) For the baseline scenario, all costs are specified as absolutes; for the action alternatives, all costs are incremental and are specified as the difference between the action alternative and the baseline scenario.

(2) For light duty vehicles (passenger cars, class-1 light duty trucks, and class-2a light duty trucks), one credit equates to one mile per 10 gallons. For medium duty vehicles (class-2a light duty trucks and class-3 light duty trucks), one credit equates to one gallon per 10k miles.

B.3 Societal Effects Report and Societal Costs Report

The *Societal Effects Report* contains industry-wide summary of energy and emissions effects, while the *Societal Costs Report* contains corresponding industry-wide summary of consumer and social costs for each model year and scenario analyzed. The modeling system generates two versions of each report, where in one, the results are reported by vehicle class (LDV, LDT12a, LDT2b3), while in the other, the results are reported by regulatory class (PC, LT, LT2b3). In each case, the results are aggregated for the entire fleet as well. Most of the metrics, which are reported independently by model year, are further summed (or averaged) over the entire analysis period.

The *Societal Effects Report* also disaggregates energy and emissions effects by fuel type, as well as providing aggregate totals across all fuels. The report contains calculated levels of energy consumed by fuel type in quads, thousands of gallons, and thousands of native units during the full useful life of all vehicles sold in each model year. For liquid fuel types (gasoline, diesel, and E85), amount of gallons consumed is specified in their native units (for example, gallons of E85). For non-liquid fuel types (electricity, hydrogen, CNG), amount of gallons consumed is specified in gasoline equivalent gallons. Additionally, energy consumption in native units is specified for electricity in mW-h, and for hydrogen and CNG in Mcf. Full useful life travel (in thousands of miles) and average fuel economy levels are also presented to provide a basis for comparison. The rated fuel economy levels reported are not comparable to the value of achieved CAFE standard shown in the compliance report. The values contained in the Societal Effects Report are computed as total VMT divided by total gallons (with the effect of the on-road gap backed out), and do not incorporate some of the compliance credits.

The *Societal Effects Report* also presents estimates of full fuel cycle carbon dioxide and criteria pollutant emissions by fuel type. As shown in Table 34 below, carbon dioxide emissions are reported in million 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 metric tons.

In the *Societal Effects Report*, for the baseline scenario, VMT, energy use, fatalities, and all emissions are specified as absolutes. For the action alternatives, these values are incremental and are specified as the difference between the action alternative and the baseline scenario.

The *Societal Costs Report* contains monetized consumer and social costs including fuel expenditures, travel and refueling value, economic and external costs arising from additional vehicle use, as well as owner and societal costs associated with emissions damage. In all cases, these costs 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-2013 dollars. Chapter Three, Section 6 of the primary text discusses these types of costs and benefits in greater detail, and Appendix A (Model Inputs) discusses corresponding input assumptions.

In the *Societal Costs Report*, for the baseline scenario, all costs are specified as absolutes. For the action alternatives, all costs are incremental and are specified as the difference between the action alternative and the baseline scenario.

Table 34 below lists the full contents of the *Societal Effects Report* and Table 35 lists the full contents of the *Societal Costs Report*.

Table 34. Societal Effects Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "TOTAL" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal effects are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Veh-Class	text	The vehicle class for which the societal effects are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal effects are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Rated FE	mpg	The average fuel economy rating of vehicles. Note, this value is not comparable to the value of achieved CAFE standard shown in the compliance report; this value is computed as total VMT divided by total gallons (with the effect of the on-road gap backed out), and does not incorporate some of the compliance credits.
On-road FE	mpg	The average on-road fuel economy rating of vehicles.
Fuel Share	ratio	The average fuel share, indicating the amount of miles driven by all vehicles on each fuel type.
Curb Weight	lbs.	Average curb weight of analyzed vehicles.
Footprint	sq.ft.	Average footprint of analyzed vehicles.
Work Factor	lbs.	Average work-factor of analyzed vehicles. This value is reported only when the vehicles analyzed are subject to the work-factor based functional standards.
Sales	units	Total production of vehicles for sale for a specific model year, regulatory or vehicle class, and fuel type (as well as sum across any of the attributes, where applicable).
kVMT	miles (k)	Thousands of miles traveled by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Quads	quads	Energy used by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
kGallons	gallons (k)	Amount of gallons of liquid fuel consumed, or amount of gasoline equivalent gallons of fuel consumed (for non-liquid fuel types), by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
kUnits	varies	Amount of energy consumed by all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type, where the units of measure vary based on fuel type. For liquid fuel types (gasoline, e85, diesel, b20, LNG, LPG), the units are specified in thousands of gallons; for electricity, the units are specified in mW-h; for hydrogen and CNG, the units are specified in Mcf.
Fatalities	units	Amount of fatalities resulting from reduction in vehicle curb weight and increases in VMT due to the rebound effect, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CO (t)	metric-tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
VOC (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
NOx (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
SO2 (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
PM (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.

CO2 (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CH4 (t)	metric-tons	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
N2O (t)	metric-tons	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Acetaldehyde (t)	metric-tons	Amount of Acetaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Acrolein (t)	metric-tons	Amount of Acrolein emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Benzene (t)	metric-tons	Amount of Benzene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Butadiene (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Formaldehyde (t)	metric-tons	Amount of Formaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
DPM10 (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
MTBE (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.

Table 35. Societal Costs Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. A value of "TOTAL" is used to represent the sums (or averages) across all model years for some of the outputs, where applicable.
Reg-Class	text	The regulatory class for which the societal costs are reported. When multiple regulatory classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all regulatory classes for some of the outputs, where applicable.
Veh-Class	text	The vehicle class for which the societal costs are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal costs are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Disc-Rate	number	Social discount rate applied to future benefits. A value of 0 indicates undiscounted costs.
Pre-Tax Fuel Cost	dollars (k)	Total pre-tax fuel expenditures accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Fuel Tax Cost	dollars (k)	Total fuel tax revenues accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Retail Fuel Costs	dollars (k)	Total retail fuel expenditures (pre-tax fuel cost + fuel tax cost) accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Drive Surplus	dollars (k)	Benefits from the additional driving that results from improved fuel economy, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Refuel Surplus	dollars (k)	Benefits from reduced refueling frequency due to the extended vehicle range and improved fuel economy, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Market Externalities	dollars (k)	Economic costs of oil imports not accounted for by price, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Congestion Costs	dollars (k)	Congestion costs from additional vehicle use, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Accident Costs	dollars (k)	Accident costs from additional vehicle use, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Noise Costs	dollars (k)	Noise costs from additional vehicle use, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
Fatality Costs	dollars (k)	Cost from additional fatalities resulting from reduction in vehicle curb weight, accumulated across all vehicles over their lifetime for a specific model year, regulatory or vehicle class, and fuel type.
CO Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Monoxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
VOC Damage Costs	dollars (k)	Owner and societal costs arising from Volatile Organic Compounds damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
NOx Damage Costs	dollars (k)	Owner and societal costs arising from Nitrogen Oxides damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
SO2 Damage Costs	dollars (k)	Owner and societal costs arising from Sulfur Dioxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
PM Damage Costs	dollars (k)	Owner and societal costs arising from Particulate Matter damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CO2 Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Dioxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
CH4 Damage Costs	dollars (k)	Owner and societal costs arising from Methane damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
N2O Damage Costs	dollars (k)	Owner and societal costs arising from Nitrous Oxide damage, aggregated over the lifetime of all vehicles for a specific model year, regulatory or vehicle class, and fuel type.
Total Consumer Costs	dollars (k)	Total consumer costs accumulated by the industry for a specific model year, regulatory or vehicle class, and fuel type. The consumer costs are the sum of: retail fuel costs, drive surplus, and refueling surplus.
Total Social Costs	dollars (k)	Total social costs accumulated by the industry for a specific model year, regulatory or vehicle class, and fuel type. The social costs are the sum of: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (CO, VOC, NOx, SO2, PM, CO2, CH4, and N2O).

B.4 Annual Societal Effects Report and Annual Societal Costs Report

The *Annual Societal Effects Report* and the *Annual Societal Costs Report* contain similar results as the *Societal Effects Report* and the *Societal Costs Report*, except these outputs further disaggregate the results by calendar year. Table 36 lists the full contents of the *Annual Societal Effects Report* and Table 37 lists the full contents of the *Annual Societal Costs Report*. The annual reports produce results as absolutes for the baseline and action alternatives.

Table 36. Annual Societal Effects Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. When "Fleet Analysis" option is enabled during modeling, the range of years is extended to include historic and future model years.
Age	integer	The vehicle's vintage, ranging from 0 to 39, where 0 corresponds to a vehicle's first year on the road.
Calendar Year	calendar year	Calendar years analyzed for the effects calculations.
Veh-Class	text	The vehicle class for which the societal costs are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal costs are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Fleet	units	Total on-road fleet for a specific model year, vehicle age, vehicle class, and fuel type.
kVMT	miles (k)	Thousands of miles traveled by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Quads	quads	Energy used by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
kGallons	gallons (k)	Amount of gallons of liquid fuel consumed, or amount of gasoline equivalent gallons of fuel consumed (for non-liquid fuel types), by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
kUnits	varies	Amount of energy consumed by all vehicles for a specific model year, vehicle age, vehicle class, and fuel type, where the units of measure vary based on fuel type. For liquid fuel types (gasoline, e85, diesel, b20, LNG, LPG), the units are specified in thousands of gallons; for electricity, the units are specified in mW-h; for hydrogen and CNG, the units are specified in Mcf.
Fatalities	units	Amount of fatalities resulting from reduction in vehicle curb weight and increases in VMT due to the rebound effect, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Upstream (t)	metric-tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Upstream (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Upstream (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Upstream (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Upstream (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Upstream (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Upstream (t)	metric-tons	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Upstream (t)	metric-tons	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acetaldehyde Upstream (t)	metric-tons	Amount of Acetaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.

Acrolein Upstream (t)	metric-tons	Amount of Acrolein emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Benzene Upstream (t)	metric-tons	Amount of Benzene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Butadiene Upstream (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Formaldehyde Upstream (t)	metric-tons	Amount of Formaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
DPM10 Upstream (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
MTBE Upstream (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Tailpipe (t)	metric-tons	Amount of Carbon Monoxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Tailpipe (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Tailpipe (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Tailpipe (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Tailpipe (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Tailpipe (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Tailpipe (t)	metric-tons	Amount of Methane emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Tailpipe (t)	metric-tons	Amount of Nitrous Oxide emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acetaldehyde Tailpipe (t)	metric-tons	Amount of Acetaldehyde emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acrolein Tailpipe (t)	metric-tons	Amount of Acrolein emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Benzene Tailpipe (t)	metric-tons	Amount of Benzene emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Butadiene Tailpipe (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Formaldehyde Tailpipe (t)	metric-tons	Amount of Formaldehyde emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
DPM10 Tailpipe (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
MTBE Tailpipe (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Total (t)	metric-tons	Amount of Carbon Monoxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Total (t)	metric-tons	Amount of Volatile Organic Compounds emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Total (t)	metric-tons	Amount of Nitrogen Oxides emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Total (t)	metric-tons	Amount of Sulfur Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Total (t)	metric-tons	Amount of Particulate Matter (diameter of ~2.5 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.

CO2 Total (mmt)	million metric-tons	Amount of Carbon Dioxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Total (t)	metric-tons	Amount of Methane emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Total (t)	metric-tons	Amount of Nitrous Oxide emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acetaldehyde Total (t)	metric-tons	Amount of Acetaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Acrolein Total (t)	metric-tons	Amount of Acrolein emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Benzene Total (t)	metric-tons	Amount of Benzene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Butadiene Total (t)	metric-tons	Amount of 1,3-Butadiene emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Formaldehyde Total (t)	metric-tons	Amount of Formaldehyde emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
DPM10 Total (t)	metric-tons	Amount of Diesel Particulate Matter (diameter of ~10 micrometers) emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
MTBE Total (t)	metric-tons	Amount of Methyl Tertiary Butyl Ether emissions generated from domestic crude petroleum extraction, transportation, and refining, from gasoline transportation, storage, and distribution, and from vehicle operation, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.

Table 37. Annual Societal Costs Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period. When "Fleet Analysis" option is enabled during modeling, the range of years is extended to include historic and future model years.
Age	integer	The vehicle's vintage, ranging from 0 to 39, where 0 corresponds to a vehicle's first year on the road.
Calendar Year	calendar year	Calendar years analyzed for the effects calculations.
Veh-Class	text	The vehicle class for which the societal costs are reported. When multiple vehicle classes are present in the output, a value of "TOTAL" is used to represent the sums (or averages) across all vehicle classes for some of the outputs, where applicable.
Fuel Type	text	The fuel type for which the societal costs are reported. A value of "TOTAL" is used to represent the sums (or averages) across all fuel types for some of the outputs, where applicable.
Disc-Rate	number	Social discount rate applied to future benefits. A value of 0 indicates undiscounted costs.
Pre-Tax Fuel Cost	dollars (k)	Total pre-tax fuel expenditures accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Fuel Tax Cost	dollars (k)	Total fuel tax revenues accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Retail Fuel Costs	dollars (k)	Total retail fuel expenditures (pre-tax fuel cost + fuel tax cost) accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Drive Surplus	dollars (k)	Benefits from the additional driving that results from improved fuel economy, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Refuel Surplus	dollars (k)	Benefits from reduced refueling frequency due to the extended vehicle range and improved fuel economy, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Market Externalities	dollars (k)	Economic costs of oil imports not accounted for by price, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Congestion Costs	dollars (k)	Congestion costs from additional vehicle use, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Accident Costs	dollars (k)	Accident costs from additional vehicle use, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Noise Costs	dollars (k)	Noise costs from additional vehicle use, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Fatality Costs	dollars (k)	Cost from additional fatalities resulting from reduction in vehicle curb weight, accumulated across all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Monoxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
VOC Damage Costs	dollars (k)	Owner and societal costs arising from Volatile Organic Compounds damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
NOx Damage Costs	dollars (k)	Owner and societal costs arising from Nitrogen Oxides damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
SO2 Damage Costs	dollars (k)	Owner and societal costs arising from Sulfur Dioxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
PM Damage Costs	dollars (k)	Owner and societal costs arising from Particulate Matter damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CO2 Damage Costs	dollars (k)	Owner and societal costs arising from Carbon Dioxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
CH4 Damage Costs	dollars (k)	Owner and societal costs arising from Methane damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
N2O Damage Costs	dollars (k)	Owner and societal costs arising from Nitrous Oxide damage, aggregated for all vehicles for a specific model year, vehicle age, vehicle class, and fuel type.
Total Consumer Costs	dollars (k)	Total consumer costs accumulated by the industry for a specific model year, vehicle age, vehicle class, and fuel type. The consumer costs are the sum of: retail fuel costs, drive surplus, and refueling surplus.
Total Social Costs	dollars (k)	Total social costs accumulated by the industry for a specific model year, vehicle age, vehicle class, and fuel type. The social costs are the sum of: pre-tax fuel costs, drive surplus, refueling surplus, market externalities, congestion costs, accident costs, noise costs, fatality costs, and emissions damage costs (CO, VOC, NOx, SO2, PM, CO2, CH4, and N2O).

B.5 Vehicles Report

The *Vehicles Report* contains disaggregate vehicle-level summary of compliance model results, providing a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed. The report includes basic vehicle characteristics (such as vehicle code, manufacturer, engine and transmission used, curb weight, footprint, and sales volumes), fuel economy information (before and after the analysis), final technology utilization, and cost metrics associated with application of additional technology.

The vehicle's fuel economy ratings prior to the start of the analysis as well as at the end of each compliance model year are presented. The fuel economy values are specified per fuel type (wherever applicable) in addition to an overall value, which used for compliance purposes. For multi-fuel vehicles, the multiple fuel economy ratings are combined according to the statutory requirements. For flex-fuel vehicles (those that operate on gasoline and ethanol-85), only the gasoline fuel economy rating is considered for compliance. For plug-in hybrid/electric vehicles (PHEVs operating on gasoline and electricity), the overall fuel economy rating is harmonically averaged based on the share of each fuel type. The vehicle's fuel share indicates the amount of miles driven by the vehicle on each fuel type. For vehicles operating on a single fuel (*e.g.*, gasoline, diesel, or electricity), the fuel share for that fuel type only is specified. For vehicles operating on multiple fuels (FFVs and PHEVs), the fuel shares are specified for gasoline and ethanol-85 or for gasoline and electricity.

The *Vehicles Report* provides initial and final sales volumes as well as initial and final MSRPs. The initial sales and MSRP represent the starting values as obtained from the input file, and do not reflect changes associated with the modeling analysis. The final sales volumes are specified by model year and will typically match the initial values, unless modeling options for sales mixing are selected. The final MSRPs are specified by model year as well, and incorporate additional costs arising from technology application or fine payment.

Table 38 below list the full contents of the *Vehicles Report*.

Table 38. Vehicles Report

Column	Units	Contents
Scenario	integer	Unique index of the scenario, where 0 represents the baseline, while 1 and above represent the action alternatives.
Scenario Name	text	A short name describing the key features of the scenario.
Model Year	model year	Model years analyzed during the study period.
Manufacturer	text	Manufacturers analyzed during the study period.
Veh Index	integer	Unique index assigned to each vehicle by the modeling system during runtime.
Veh Code	integer	Index of the vehicle (unique per manufacturer), as read from the input file.
Brand	text	Vehicle brand.
Model	text	Vehicle model.
Name Plate	text	Vehicle nameplate.
Platform	text	Name of the platform used by a vehicle.
Plt Version	text	Revision of the platform used by a vehicle. This field lists the platform version as "baseline", if the vehicle is using an original and unmodified platform. Alternatively, this field shows the model year, signifying the revision of the intial platform that the vehicle has inherited.
Powertrain	text	Vehicle's powertrain type in a specific model year. Available options are: Conventional, MHEV for mild hybridization (including 12 volt micro-hybrid and belt- or crank-mounted integrated starter/generator), SHEV for strong hybrid/electric vehicle, PHEV for plug-in hybrid/electric vehicle, BEV for battery electric vehicle, and FCV for fuel cell vehicle.
Veh Power Initial	HP	Initial power rating of a vehicle.
Veh Power	HP	Final power rating of a vehicle.
Eng Code	integer	Index of the engine used by a vehicle.
Eng Fuel Initial	text	Fuel used by the starting engine, before any modifications were made by the modeling system. Available options are: G for gasoline, D for diesel, and CNG for compressed natural gas.
Eng Type Initial	text	Brief information about the starting engine, before any modifications were made by the modeling system. The field includes: engine horsepower, displacement, configuration, number of cylinders, and aspiration.
Eng Version	text	Revision of the engine used by a vehicle. This field lists the engine version as "baseline", if the vehicle is using an original and unmodified engine. Alternatively, this field shows the model year, signifying the revision of the intial engine that the vehicle has inherited.
Eng Fuel	text	Fuel used by the engine in a specific model year.
Eng Type	text	Brief information about the engine in a specific model year. At present, only the aspiration of the engine is shown, since other attributes are assumed to remain unchanged.
Trn Code	integer	Index of the transmission used by a vehicle.
Trn Type Initial	text	Brief information about the starting transmission, before any modifications were made by the modeling system. This field includes: transmission type (A=automatic, M=manual, CVT=continuously variable transmission, AMT=automated manual transmission, DCT=dual-clutch transmission) and number of gears (if applicable).
Trn Version	text	Revision of the transmission used by a vehicle. This field lists the transmission version as "baseline", if the vehicle is using an original and unmodified transmission. Alternatively, this field shows the model year, signifying the revision of the intial transmission that the vehicle has inherited.
Trn Type	text	Brief information about the transmission in a specific model year. This field includes: transmission type (A=automatic, M=manual, CVT=continuously variable transmission, S=sequential transmission (AMT or DCT), HEV=unique transmission on a hybrid/electric vehicle) and number of gears (if applicable).
FE Primary Initial	mpg	Vehicle's initial fuel economy rating when operating on its primary fuel type. This represents the starting value as read from the input file.
FE Secondary Initial	mpg	Vehicle's initial fuel economy rating when operating on its secondary fuel type (if applicable). This represents the starting value as read from the input file.
FE Initial	mpg	Vehicle's overall initial fuel economy rating, before any modifications were made by the modeling system. For FFVs (gasoline/E85) and PHEVs (gasoline/electricity), the overall fuel economy rating may be harmonically averaged based on the share of each fuel type, according to the "Multi-Fuel" setting defined in the scenarios input file.
Fuel Initial	text	All fuel types initially used by the vehicle, before any modifications were made by the modeling system.
FS Initial	ratio	Vehicle's initial fuel share, indicating the amount of miles driven by the vehicle on each fuel type. Only the fuel types on which the vehicle operates are reported. This represents the starting value as read from the input file.
FE Primary Rated	mpg	Vehicle's fuel economy rating when operating on its primary fuel type, in a specific model year, taking into account the effect of technology additions made by the modeling system. This value does not include adjustment for improvements in air conditioning or off-cycle credits.
FE Secondary Rated	mpg	Vehicle's fuel economy rating when operating on its secondary fuel type (if applicable), in a specific model year, taking into account the effect of technology additions made by the modeling system. This value does not include adjustment for improvements in air conditioning or off-cycle credits.
FE Rated	mpg	Vehicle's overall fuel economy rating in a specific model year, taking into account the effect of technology additions made by the modeling system. For FFVs (gasoline/E85) and PHEVs (gasoline/electricity), the overall fuel economy rating may be harmonically averaged based on the share of each fuel type, according to the "Multi-Fuel" setting defined in the scenarios input file. This value does not include adjustment for improvements in air conditioning or off-cycle credits.

FE Primary Compliance	mpg	Vehicle's fuel economy rating when operating on its primary fuel type, in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits.
FE Secondary Compliance	mpg	Vehicle's fuel economy rating when operating on its secondary fuel type (if applicable), in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits.
FE Compliance	mpg	Vehicle's overall fuel economy rating in a specific model year, taking into account the effect of technology additions made by the modeling system, adjusted for improvements in air conditioning and off-cycle credits. For FFVs (gasoline/E85 and diesel/B20) and PHEVs (gasoline/electricity), the overall fuel economy rating may be harmonically averaged based on the share of each fuel type, according to the "Multi-Fuel" setting defined in the scenarios input file. This value is used for compliance purposes.
Fuel	text	All fuel types used by the vehicle in a specific model year.
Fuel Share	ratio	Vehicle's fuel share, indicating the amount of miles driven by the vehicle on each fuel type in a specific model year. Only the fuel types on which the vehicle operates are reported.
Veh Class	text	Vehicle's general classification (passenger vehicle: LDV; light duty truck: LDT1, LDT2a, LDT2b, LDT3; medium duty truck: MDT4, MDT5, MDT6; heavy duty truck: HDT7, HDT8). Only the passenger vehicle and light duty truck classifications are supported by the modeling system.
Reg Class	text	Vehicle's regulatory class (PassengerCar, LightTruck, or LightTruck2b3).
Tech Class	text	Vehicle's technology class (used for technology selection and application).
Safety Class	text	Vehicle's safety class (PC=Passenger Car, CM=CUV/Minivan, LT=Light Truck/SUV; used for safety calculations).
Redesign State	text	Vehicle's redesign state, whether the vehicle is being redesigned in the current model year.
Refresh State	text	Vehicle's refresh state, whether the vehicle is being refreshed in the current model year.
Platform Leader	text	A flag indicating whether a vehicle serves as the leader of the engine (E), transmission (T), and/or platform (P) that it uses. During modeling, engine, transmission, and platform technologies are first applied to a leader vehicle during the leaders redesign or refresh, and subsequently inherited on all other vehicles during their redesign/refresh years.
Sales Initial	units	Vehicle's production volumes in a specific model year. This represents the starting value as read from the input file.
Sales	units	Vehicle's final production volumes in a specific model year. If modeling options for sales mixing are used (such as the Dynamic Fleet Share Model), this value will differ from the initial production volumes; otherwise, this value will be the same the initial one.
MSRP Initial	dollars	Vehicle's initial MSRP value in a specific model year. This represents the starting value as read from the input file.
MSRP	dollars	Vehicle's final MSRP value in a specific model year, including additional costs arising from technology application or fine payment.
k.Labor Hours	hours (k)	Thousands of employment hours associated with the production of the vehicle models in a specific model year.
CW Initial	lbs.	Vehicle's initial curb weight. This represents the starting value as read from the input file.
CW	lbs.	Vehicle's final curb weight in a specific model year, taking into account any mass reduction technology applied by the modeling system.
TW Initial	lbs.	Vehicle's initial test weight, before any modifications were made by the modeling system.
TW	lbs.	Vehicle's final test weight in a specific model year, taking into account any mass reduction technology applied by the modeling system.
GVWR Initial	lbs.	Vehicle's initial GVWR, before any modifications were made by the modeling system.
GVWR	lbs.	Vehicle's final GVWR in a specific model year, taking into account any mass reduction technology applied by the modeling system.
GCWR Initial	lbs.	Vehicle's initial GCWR, before any modifications were made by the modeling system.
GCWR	lbs.	Vehicle's final GCWR in a specific model year, taking into account any mass reduction technology applied by the modeling system.
Footprint	sq.ft.	Vehicle's initial footprint. This represents the starting value as read from the input file. The vehicle's footprint does not change during the analysis.
Work Factor	lbs.	Vehicle's work factor in a specific model year. This value is reported only for vehicles that are subject to the work-factor based functional standard.
FE Target	gallons per mile	Vehicle's fuel economy target in a specific model year.
CO2 Target	grams per mile	Vehicle's CO-2 target in a specific model year.
CO2 Rating	grams per mile	Vehicle's CO-2 rating in a specific model year.
ZEV Credits	zevs	Amount of ZEV credits generated by a vehicle due to its full or partial operation on fuel types that do not generate downstream emissions. At present, PHEV's, EV's, and FCVs are ZEV credit generating vehicles.
Tech Cost	dollars	Unit costs accumulated by the vehicle model from technology application in a specific model year.

Price Increase	dollars	Increase in vehicle price accumulated by the vehicle model from technology application and fine payment in a specific model year.
Tax Credit	dollars	Amount of Federal tax credits a buyer receives for purchasing this vehicle. Tax credits are specified for strong hybrid, plug-in hybrid, and electric vehicles, only when the applicable "Tax Credit" settings are defined in the scenarios input file.
Consumer Valuation	dollars	Loss in value to the consumer due to decreased range of pure electric vehicles. This value does not apply if the vehicle is not an EV.
Rel. Value Loss	dollars	Relative loss in value to the consumer due to due to decreased operating life of pure electric vehicles. This value does not apply if the vehicle is not an EV.
Maint Cost	dollars	Unit maintenance costs accumulated by the vehicle model from technology application in a specific model year.
Repair Cost	dollars	Unit repair costs accumulated by the vehicle model from technology application in a specific model year.
Taxes/Fees	dollars	Taxes & fees paid by the consumers for purchasing a new vehicle model in a specific model year.
Financing	dollars	Financing costs paid by the consumers for purchasing a new vehicle model in a specific model year.
Insurance	dollars	Insurance costs paid by the consumers for purchasing a new vehicle model in a specific model year.
Technology (multiple columns)	text	The utilization of technologies on a vehicle model in a specific model year. The following define the utilization codes used by the modeling system: U = technology was initially in use on a base vehicle before modeling began A = technology was applied to a vehicle by the modeling system I = technology was applied to a leader of a vehicle's engine, transmission, or platform by the modeling system, and later inherited on a current follower vehicle US = technology was in use on a base vehicle, but was later superseded when another technology was applied by the modeling system AS = technology was applied to a vehicle by the modeling system, but was later superseded when another technology was applied IS = technology was inherited on a vehicle by the modeling system, but was later superseded when another technology was applied P = technology has exceed its phase-in threshold in the current model year, and thus was not applied by the modeling system X = technology is not available for application on a vehicle in the current model year <blank> = technology is available for application on a vehicle in the current model year, but the modeling system has not yet applied it

Appendix C CAFE Model Software Manual

C.1 Warnings

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

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

C.2 Notice

The CAFE Model software is a U.S. government work not subject to copyright pursuant to 17 USC 105; however, some of the third-party works used by the software are subject to usage agreements, as described below.

The button controls in the application toolbar of the CAFE Model use images from the Glaze Icon Set (version 0.4.6, released on 3/06/2006) obtained from http://www.notmart.org. All icons and/or images within the Glaze Icon Set are distributed under the GNU Lesser General Public License (LGPL), version 2.1. The version 2.1 of the GNU LGPL may be obtained from http://www.gnu.org/licenses/old-licenses/lgpl-2.1.html.

If users of the CAFE model have any questions about this notice, please contact the current administrators of the CAFE Model project.

C.3 Installation and System Requirements

The CAFE Model runs on IBM-compatible computers using the Microsoft® Windows operating system. Although the software does not have strict hardware requirements, beyond what is needed to run the operating system, a 1 GHz or faster Intel compatible processor, with at least 2 GB of physical memory (RAM) is strongly recommended. The software has been developed and tested on computers using Windows XP/7 and Windows Server 2003/2008, but may operate properly on machines using older versions of Windows (*e.g.*, Windows 2000), or newer versions (*e.g.*, Windows 8), as long as a compatible Microsoft® .NET Framework is installed.

The CAFE Model software uses Microsoft® Excel to read input files needed for modeling. As such, Excel must be installed on the system. The software also uses the Microsoft® .NET Framework, version 3.5. If the Framework is not already present, it must be installed. Instructions for downloading and installing the .NET framework are available on the Internet at http://www.microsoft.com/download/en/details.aspx?id=22.

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

Table 39. CAFE Model System Requirements

Intel compatible processor (1 GHz or faster recommended)
1 GB RAM (2 GB recommended)
10 MB hard drive space for installation (additional disk space will be required during runtime)
Microsoft® Windows XP/Vista/7/8/10 Microsoft® Windows Server 2003/2008/2012
Microsoft® .NET Framework 3.5
Microsoft® Excel 2010 or later

Once the system requirements have been met, the latest version of the CAFE Model may be obtained by contacting NHTSA or Volpe Center staff.

The current version of the software is packaged as a stand-alone executable and does not require installation. To operate the model, place the "CAFE Model.exe" file on the desktop and execute it[23].

C.4 CAFE Model Graphical User Interface

The CAFE Model Graphical User Interface (GUI) provides users with a set of tools necessary to set up and run multiple modeling test scenarios, which are commonly referred to as CAFE Model sessions. Each CAFE Model session can be configured independently, each with its own set of model inputs and settings. Once configured, the session may be saved for future runs, or executed immediately.[24] When the model runs, the system displays the progress of the compliance modeling process in each session's window.

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

To run the modeling system, click on the **CAFE Model** executable file located on the desktop. When the application launches, a **Warnings** dialog box is displayed (Figure 9). The user must read and understand the warnings listed prior to using the modeling system.

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

[24] It is recommended that users save the sessions prior to running them in order to assign a meaningful title to each session.

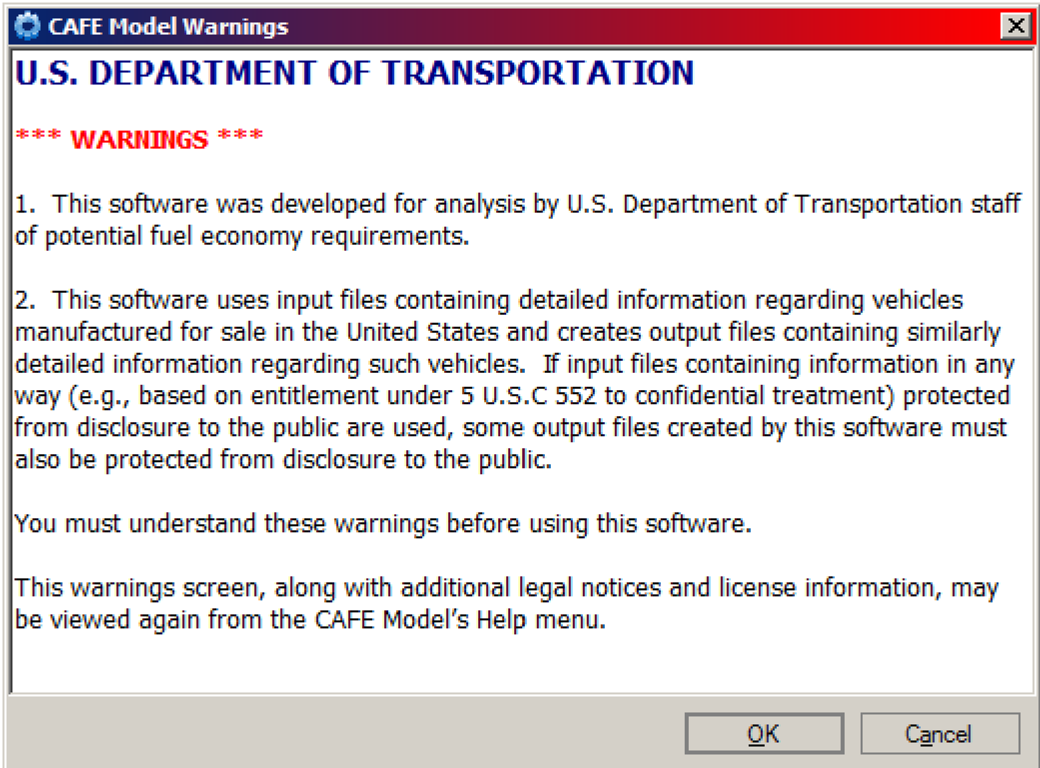

Figure 9. Warnings Dialog Box

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

C.4.1 CAFE Model Window

The main **CAFE Model** window (Figure 10) is used to create, configure, and manage CAFE modeling sessions. The main window also controls the model operation, allowing users to start and stop modeling simulation.

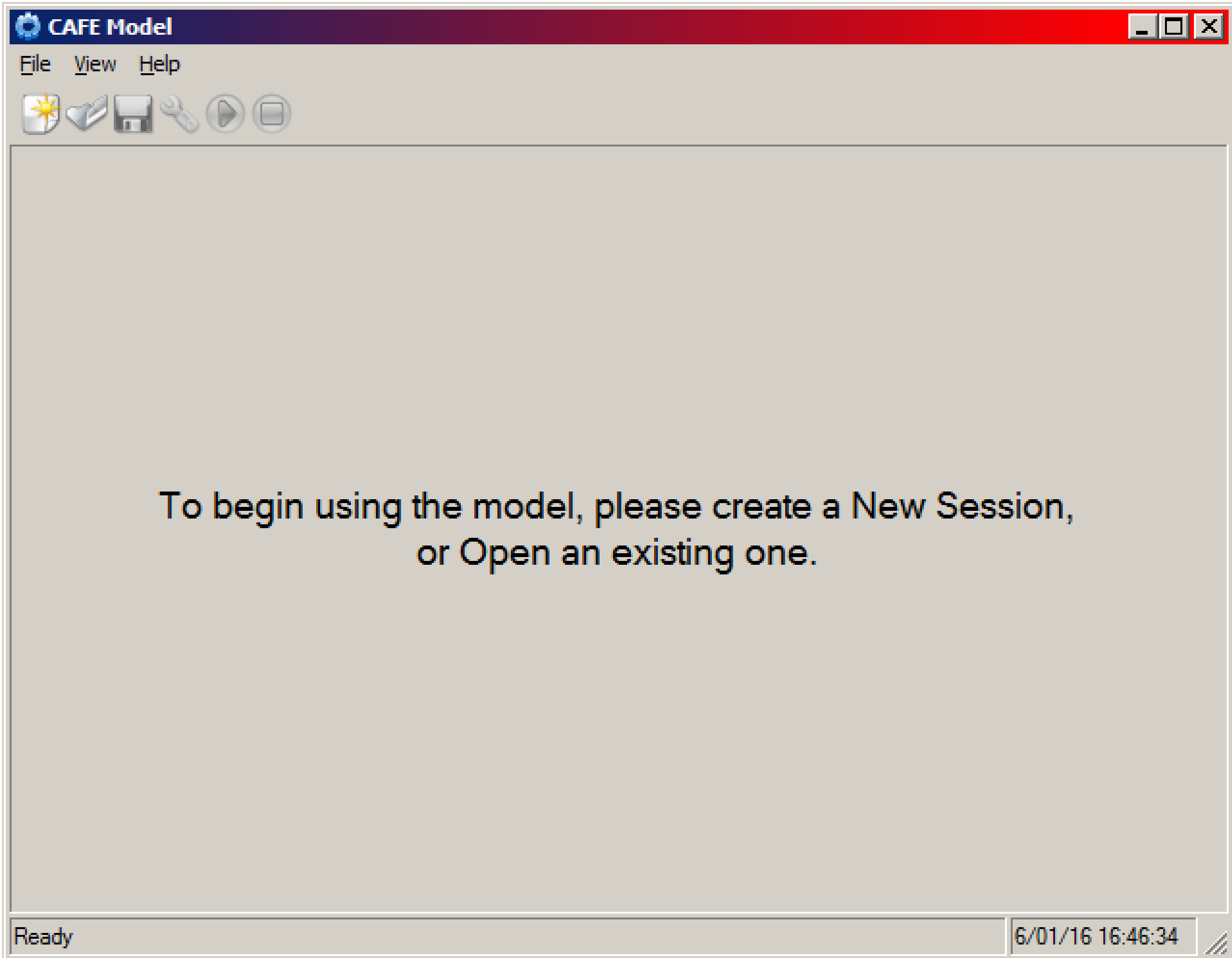

Figure 10. CAFE Model Window

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

The model GUI is operated using a simple, easy to use file-menu (Figure 11), with most commonly used shortcuts also available on the model toolbar (Figure 12). For user convenience, most of the menu entries may also be controlled using keyboard shortcuts.

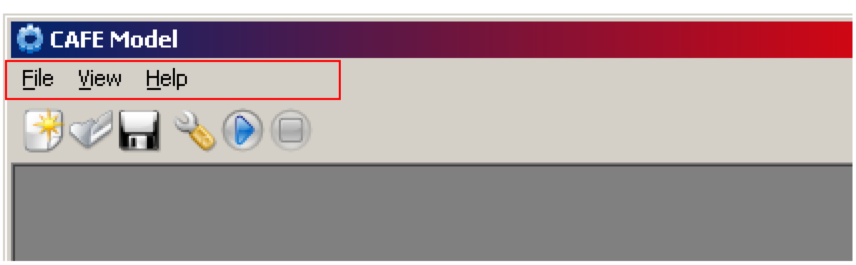

Figure 11. CAFE Model File Menu

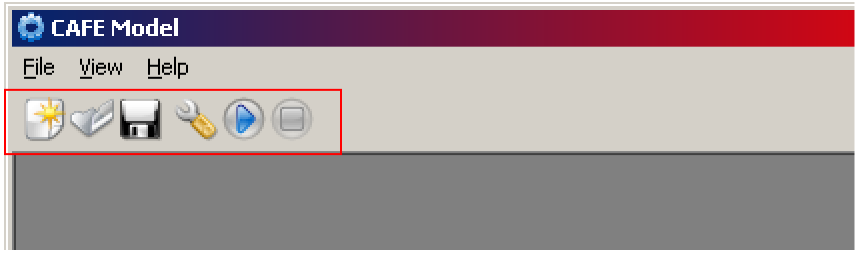

Figure 12. CAFE Model Toolbar

Some of the most commonly used file menus are:

- ***File > New Session***: Creates a new *CAFE Model Session* and displays the **Modeling Settings** window to the user.
- ***File > Open Session***: Opens an existing *CAFE Model Session*.
- ***File > Close Session***: Closes the active *CAFE Model Session*.
- ***File > Save Session***: Saves the active *CAFE Model Session*.
- ***File > Start Modeling***: Begins the modeling process for the active *CAFE Model Session*.
- ***File > Stop Modeling***: Suspends the modeling process of the active *CAFE Model Session*.
- ***File > Exit***: Exits the **CAFE Model**. If any of the modeling sessions are still opened, they will be closed prior to exiting the model.
- ***View > Modeling Settings***: Displays the **Modeling Settings** window, where all modeling options and settings may be configured.
- ***View > Output Location***: Opens the Windows Explorer and browses to the location where the output files and reports of the active session are saved.

C.4.2 Modeling Settings Window

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

C.4.2.1 General Compliance Settings Panel

The **General Compliance Settings** panel (Figure 13) is used to specify what type of modeling the user would like to run. Each model is tailored to different type of analysis, using its own set of assumptions and configuration settings. Presently, two model types are available:

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

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

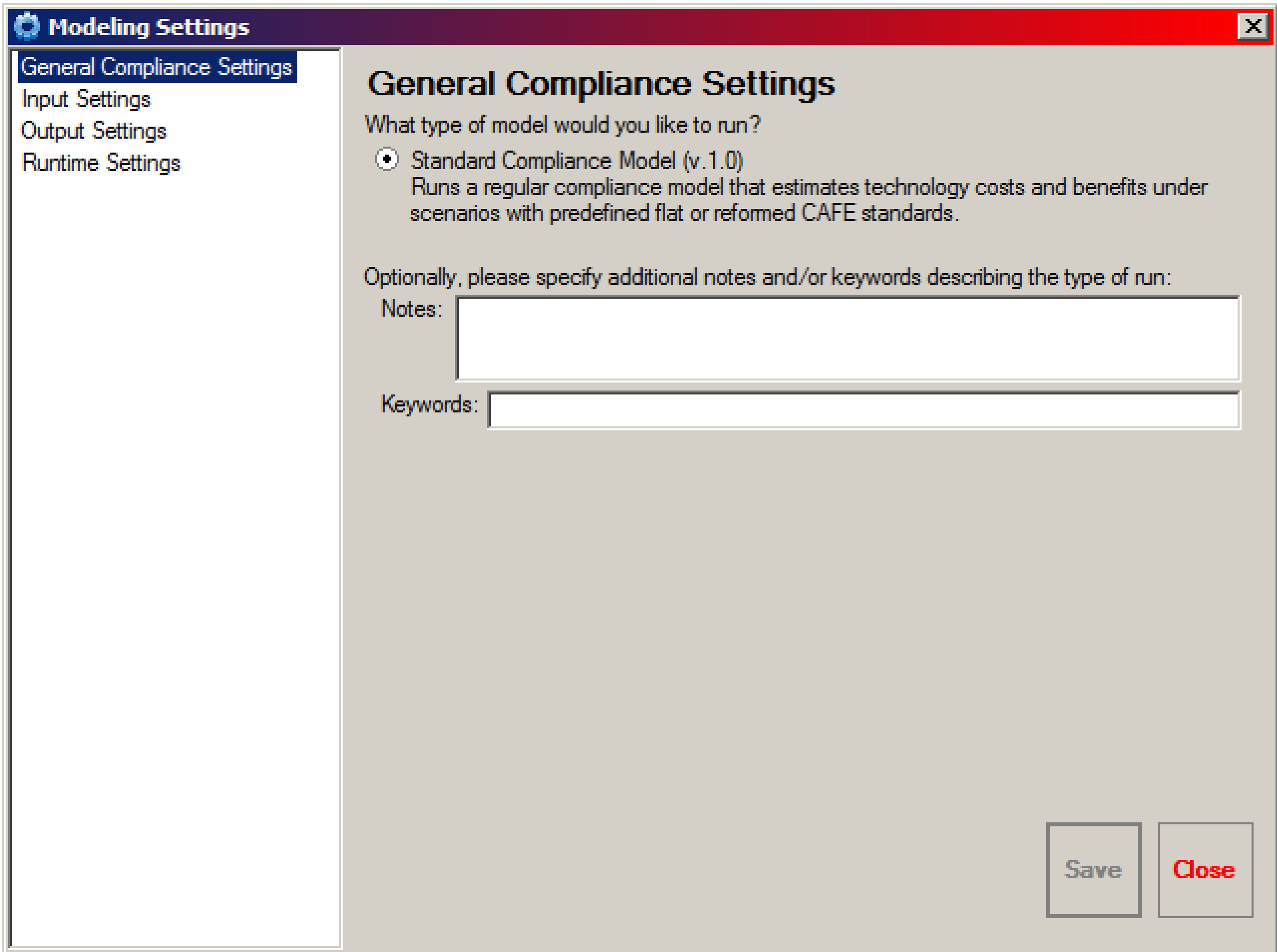

Figure 13. General Compliance Settings Panel

C.4.2.2 Input Settings Panel

On the **Input Settings** panel (Figure 14), the user can select the input data files for use with the modeling system.

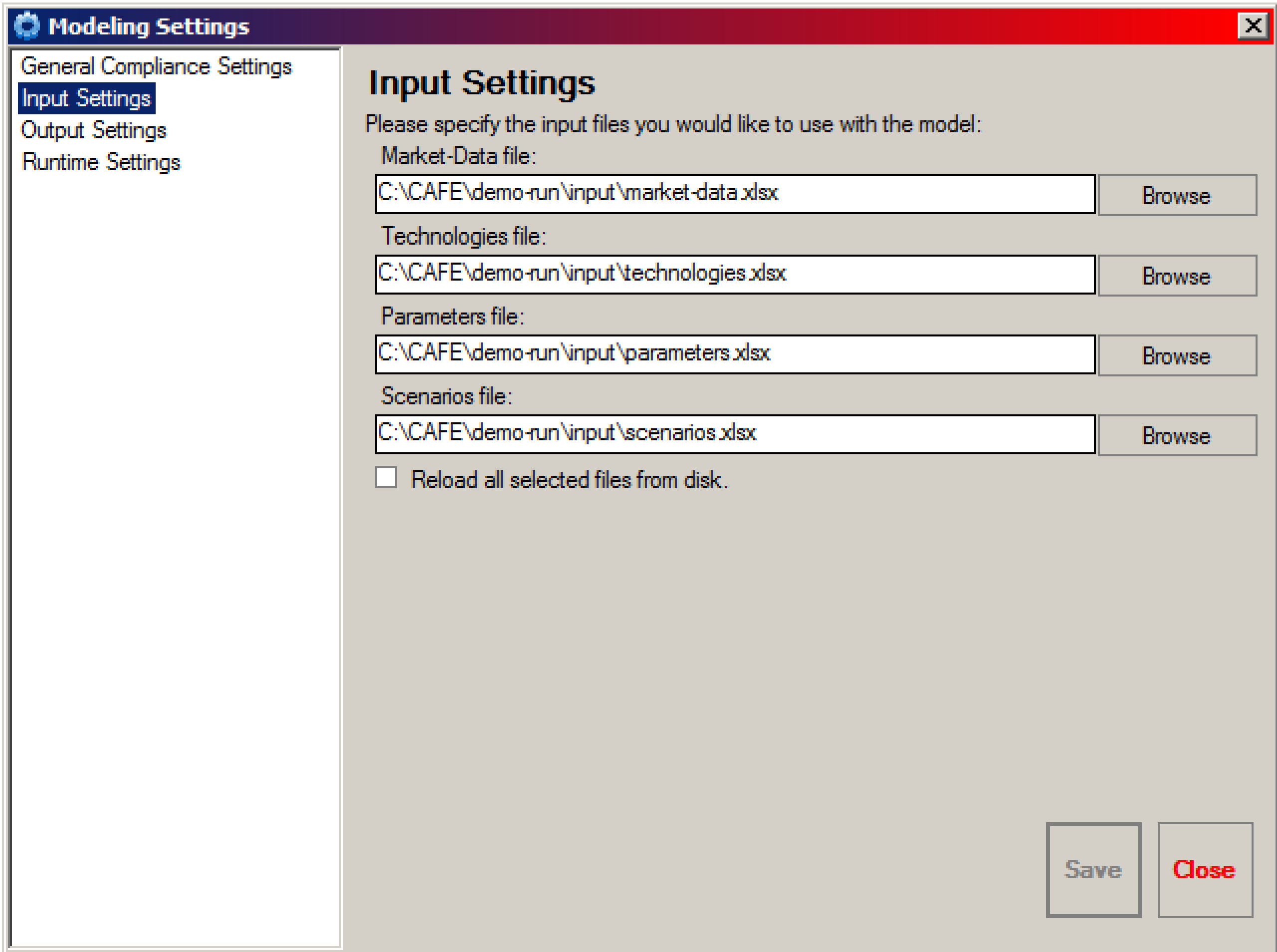

Figure 14. Input Settings Panel (1)

When selecting input files, the model will attempt to verify if an appropriate file was used. If incorrect file path is entered, an error message will be displayed (Figure 15).

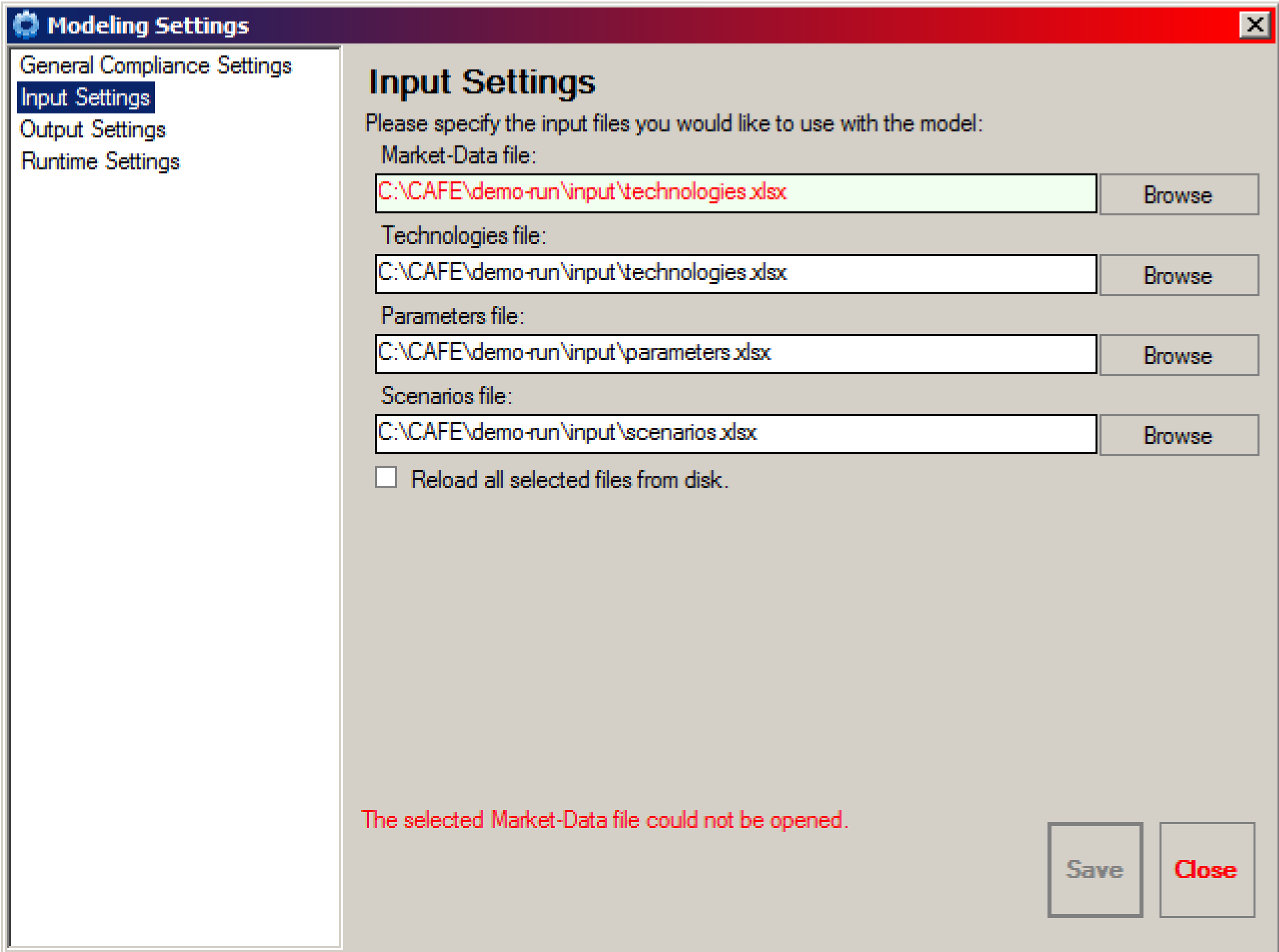

Figure 15. Input Settings Panel (2)

C.4.2.3 Output Settings Panel

The **Output Settings** panel (Figure 16) is used to configure the location where modeling results will be saved.

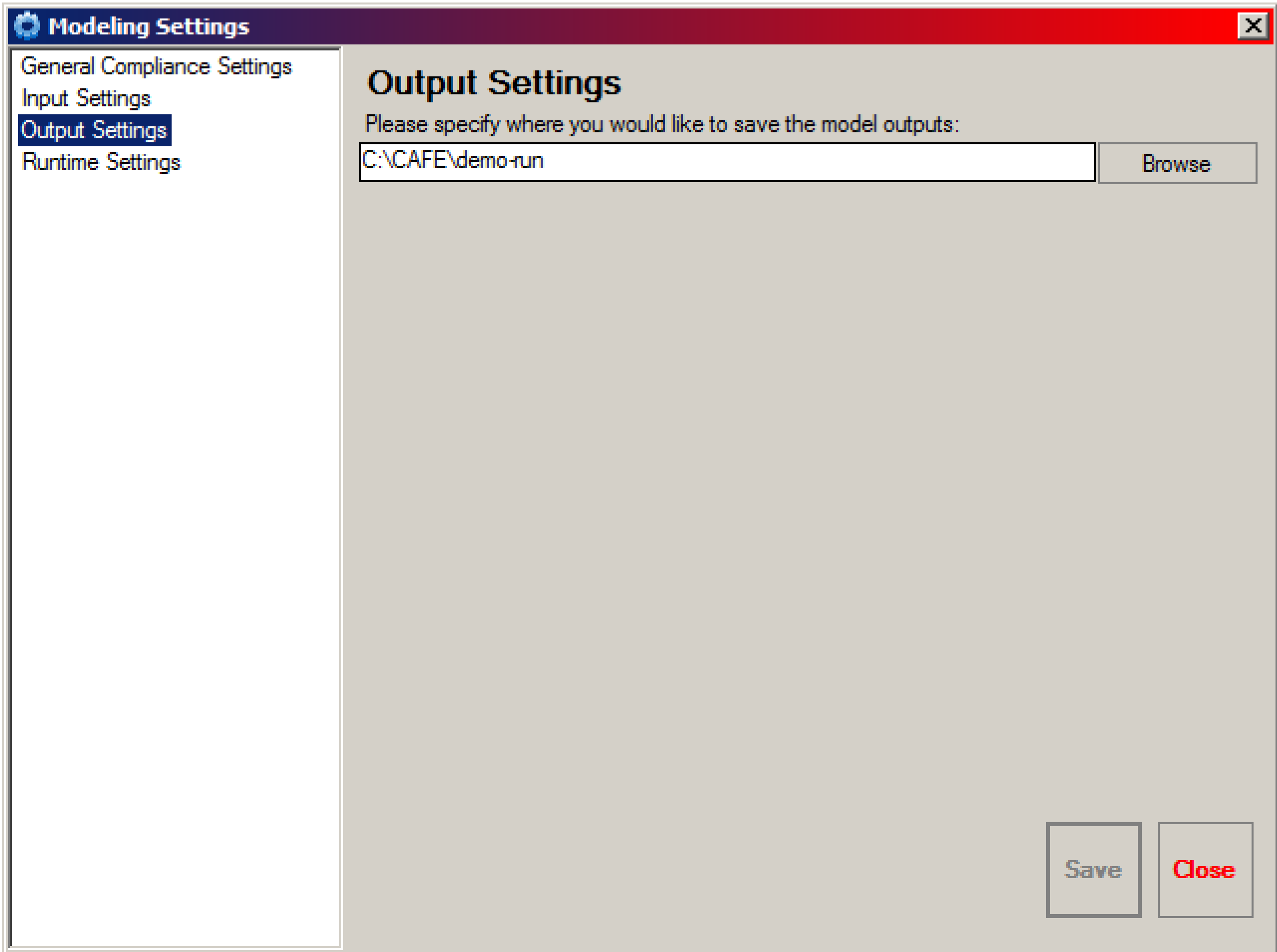

Figure 16. Output Settings Panel

The modeling system automatically generates the following seven output files (in CSV format) during runtime:

- ***Technology Utilization Report***: Provides manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Compliance Report***: Provides manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.
- ***Societal Effects Report***: Provides industry-wide summary of energy and emissions effects for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.
- ***Societal Costs Report***: Provides industry-wide summary of consumer and social costs for each model year and scenario analyzed. The model produces two versions of this output file, where the results are disaggregated by either the vehicle class and fuel type or the

regulatory class and fuel type, as well as combined across all fuels and over the entire fleet.

- ***Annual Societal Effects Report***: This output file is similar to the *Societal Effects Report*, except it further disaggregates the results by calendar year.
- ***Annual Societal Costs Report***: This output file is similar to the *Societal Costs Report*, except it further disaggregates the results by calendar year.
- ***Vehicles Report***: Provides a detailed view of the final state of each vehicle examined by the model, for each model year and scenario analyzed.

C.4.2.4 Runtime Settings Panel

The **Runtime Settings** panel (Figure 17) provides additional modeling options to further customize the model behavior, beyond what is available in the input files:

- ***Fuel Price Estimates***: Specifies whether to use the low, average, or high fuel price estimates from the parameters input file. By default, average fuel price estimates are used.
- ***CO2 Price Estimates***: Specifies whether to use low, average, high, or very-high carbon dioxide cost estimates from the parameters input file. By default, average CO2 price estimates are used.
- ***Allow Credit Trading***: Specifies whether the model should allow manufacturers to transfer credits between passenger car and light truck fleets and to carry-forward credits forward from previous model years into the analysis year.
- ***Perform Fleet Analysis Calculations***: Specifies whether the model should perform fleet analysis calculations, evaluating modeling effects for historic and forecast model years (before the first compliance model year as well as after the last compliance model year).
- ***Scale Consumer Benefits***: Specifies whether the model should scale the private consumer benefits by a specific percentage during the effects calculations. Valid values are between 0 and 100.

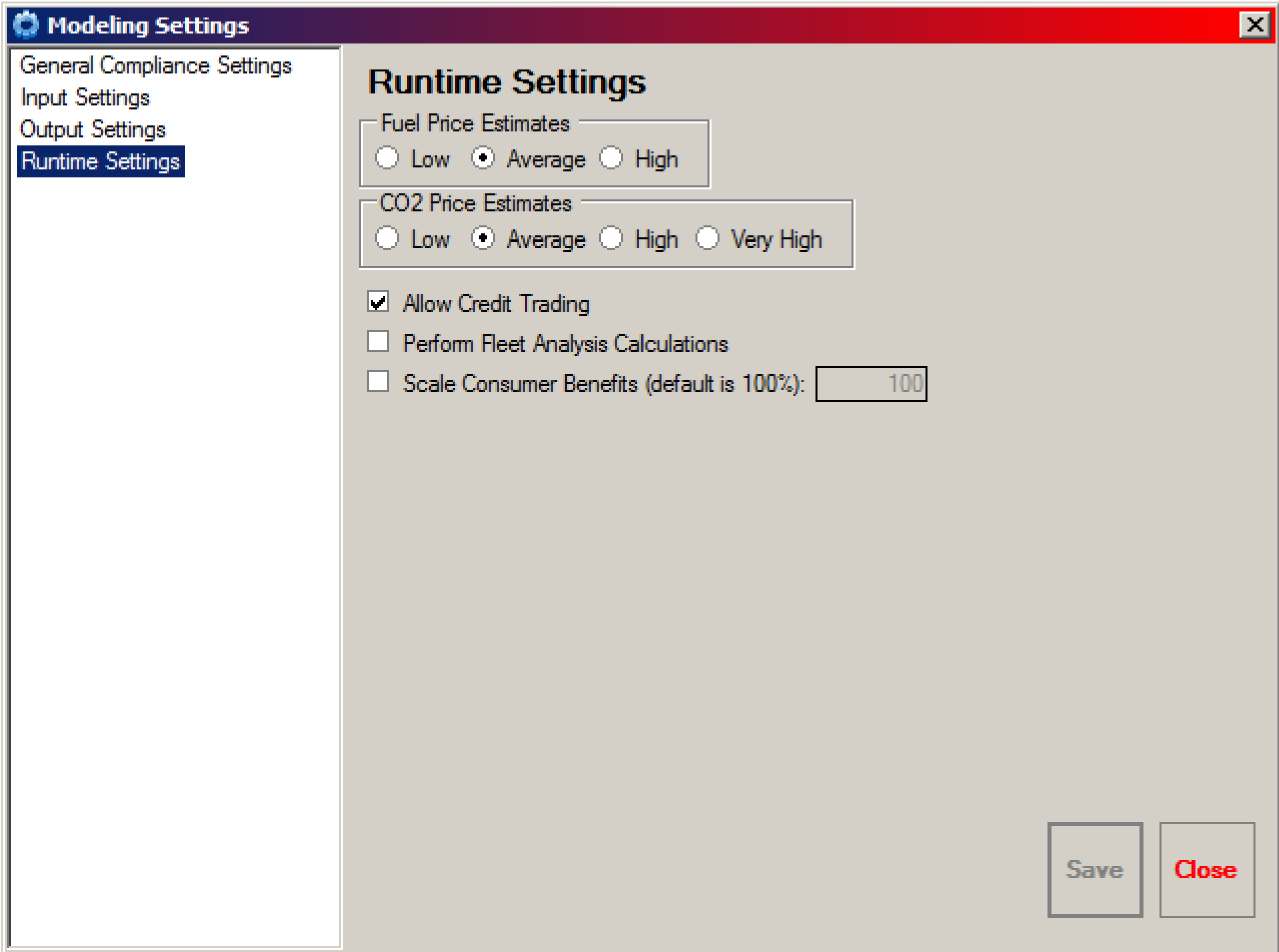

Figure 17. Runtime Settings Panel

C.5 CAFE Model Usage Examples

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

C.5.1 Example 1 – Configuring for Standard Compliance Modeling

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

- Run the CAFE Model by clicking on the **CAFE Model** executable located on the desktop. Read through the **Warnings** dialog box, and then click the **OK** button.
- Select **File** > **New Session** to create a new modeling session. The **Modeling Settings** window appears. Note the errors at the bottom of the window; these indicate that the input files have not been selected.
- On the **General Compliance Settings** panel, select the *Standard Compliance Model* as shown in Figure 18 below.

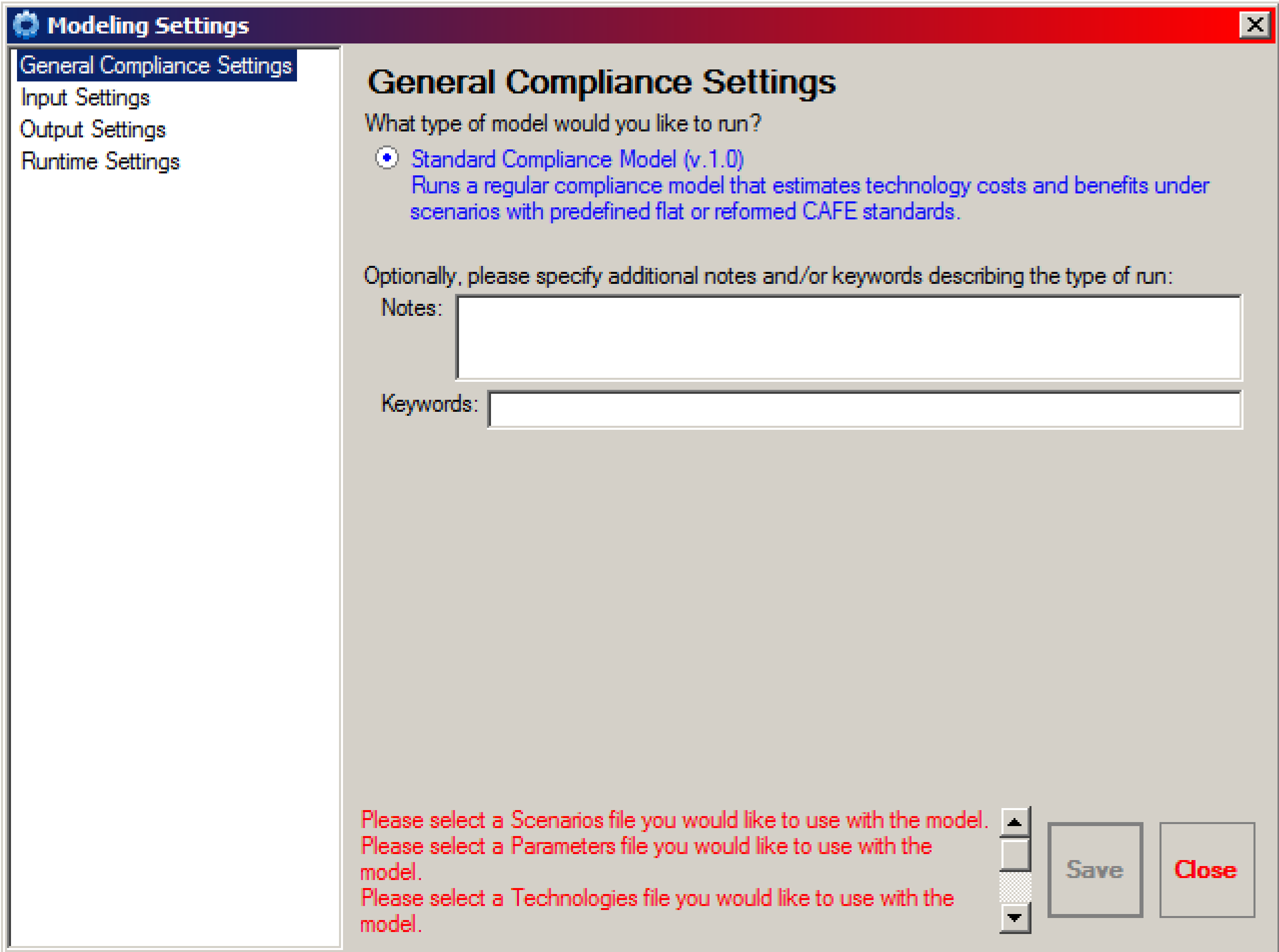

Figure 18. Select Standard Compliance Model

- Click on the **Input Settings** panel to select the input files to use for modeling (Figure 19). Note that once all the input files have been selected appropriately, the error messages disappear.

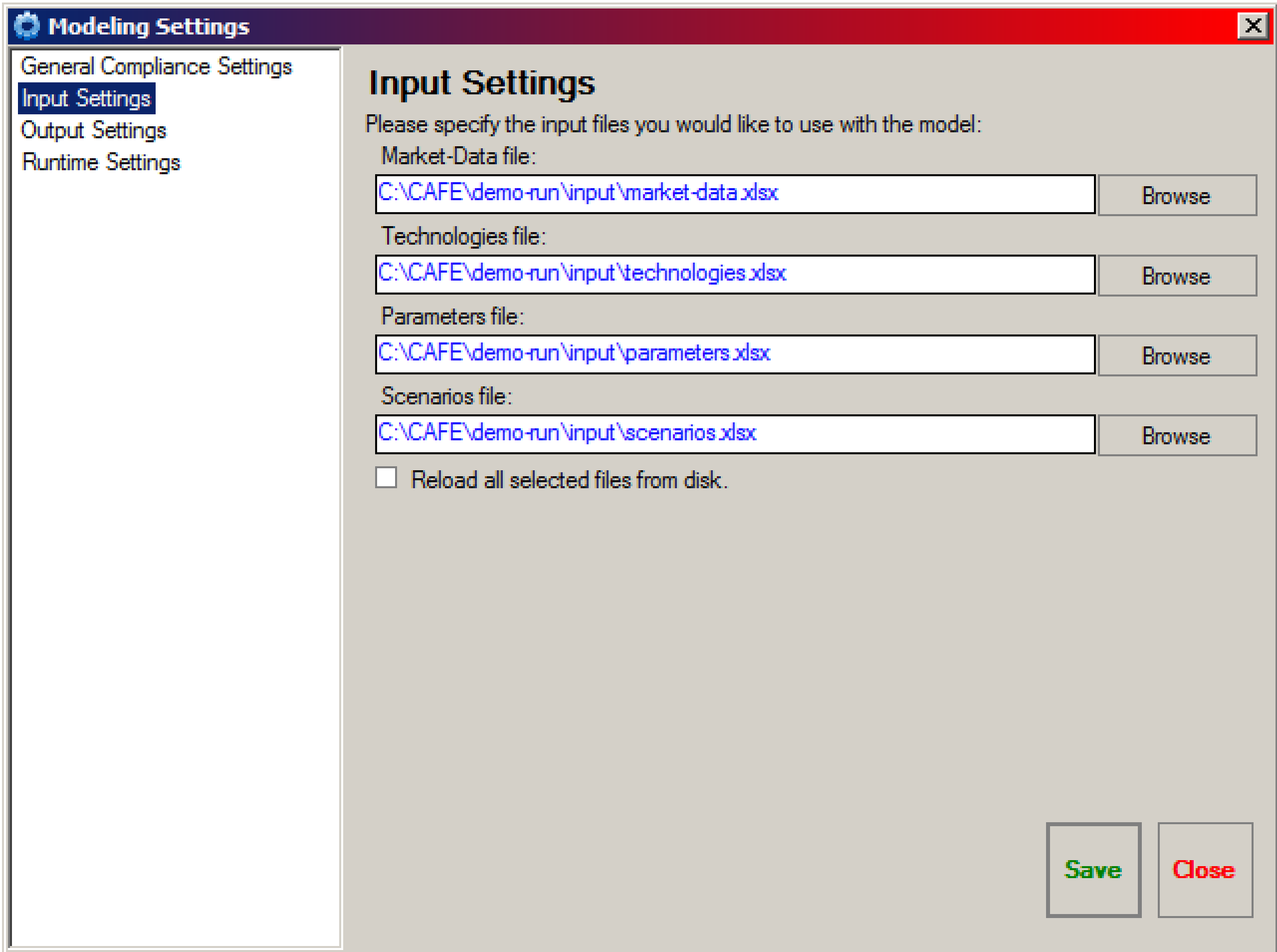

Figure 19. Select Input Files

- On the **Output Settings** panel, select the location for output files (Figure 20).

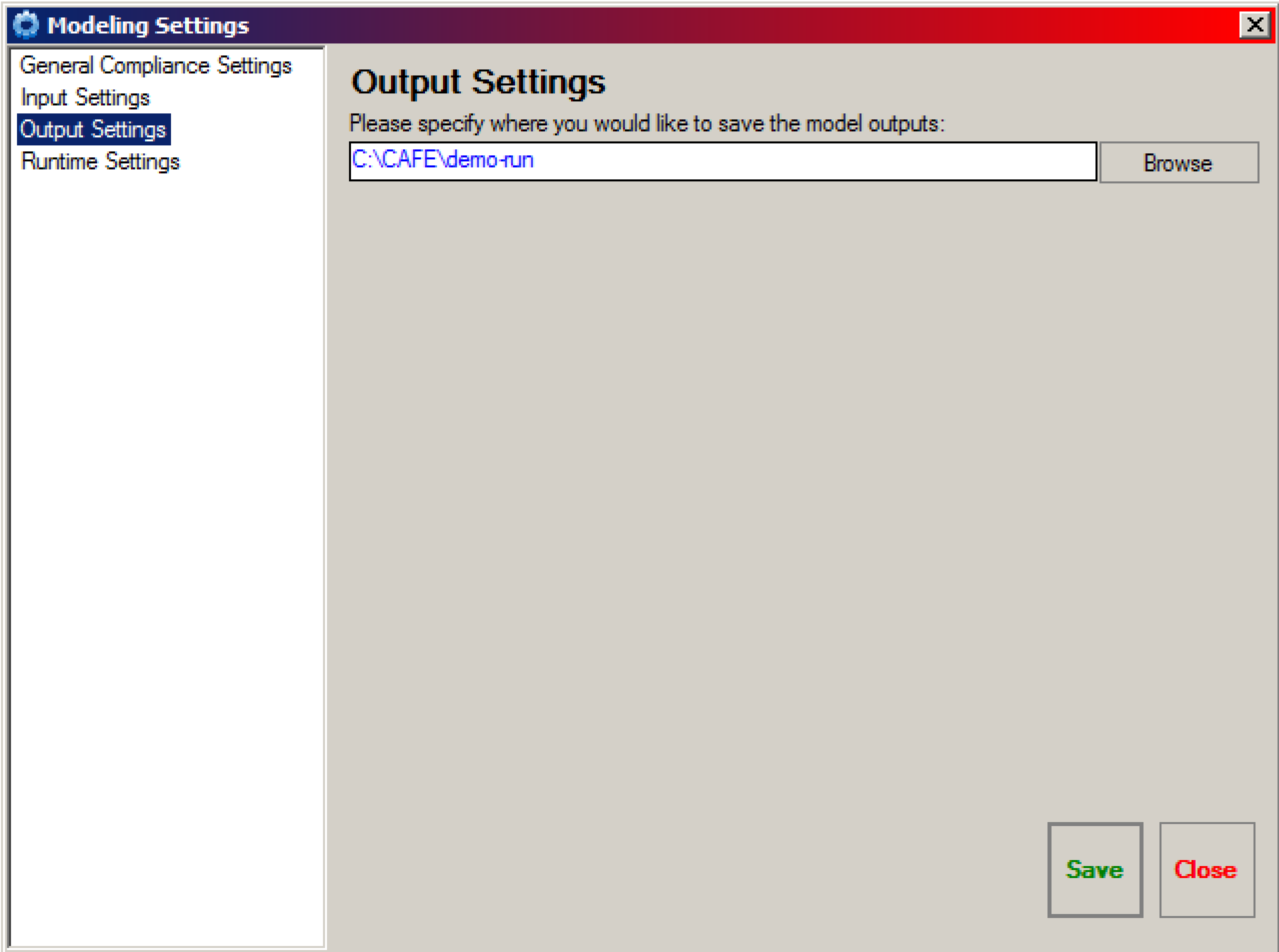

Figure 20. Select Output Location

- The **Runtime Settings** panel is not used for this exercise.
- Click the **Save** button to save the modeling settings and load the input files (Figure 21).

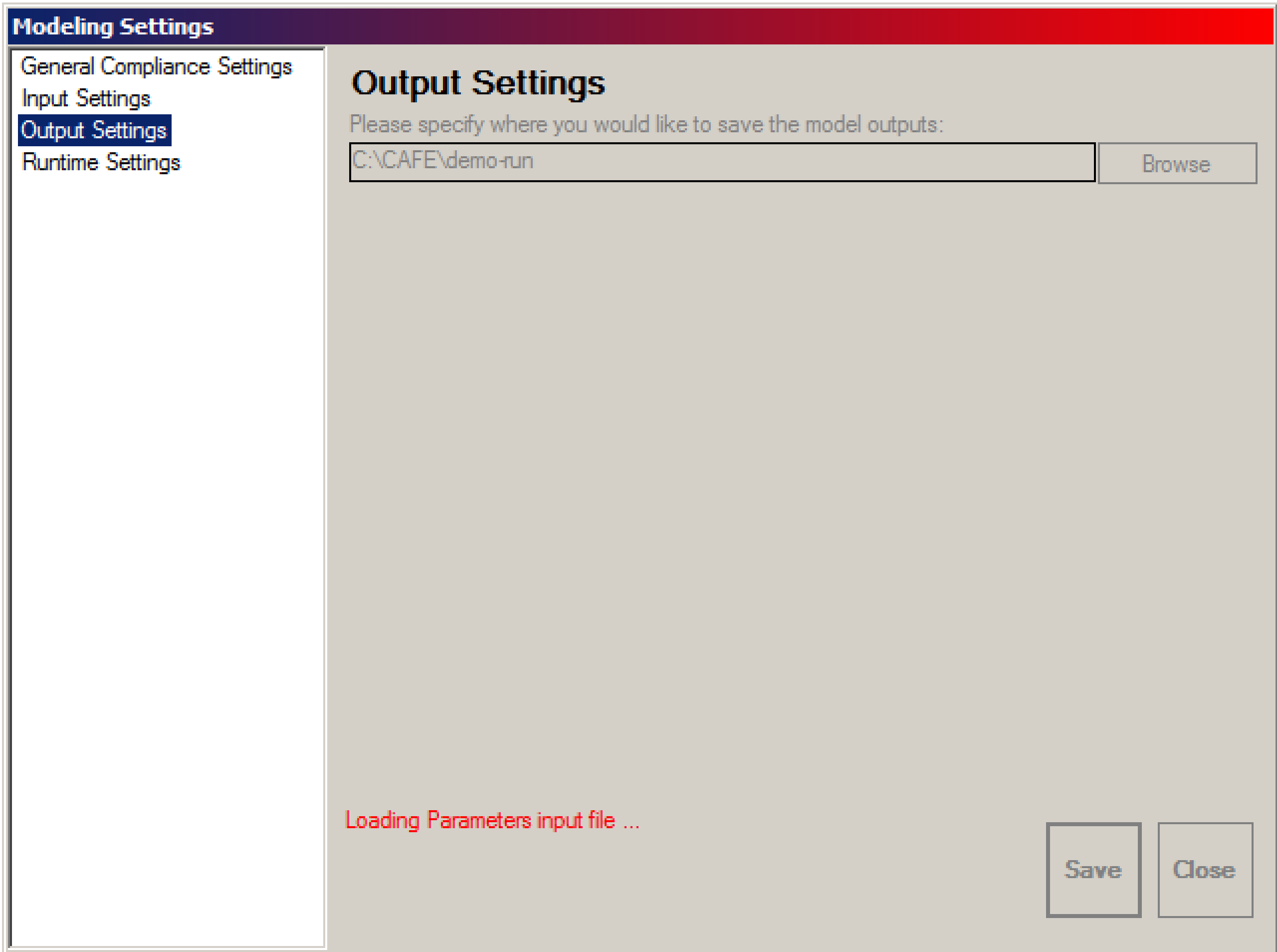

Figure 21. Save Modeling Settings

- Once loading completes, click the **Close** button to return the main **CAFE Model** window. A new *Compliance Model* session, titled "Session 1" has now been created (Figure 22).

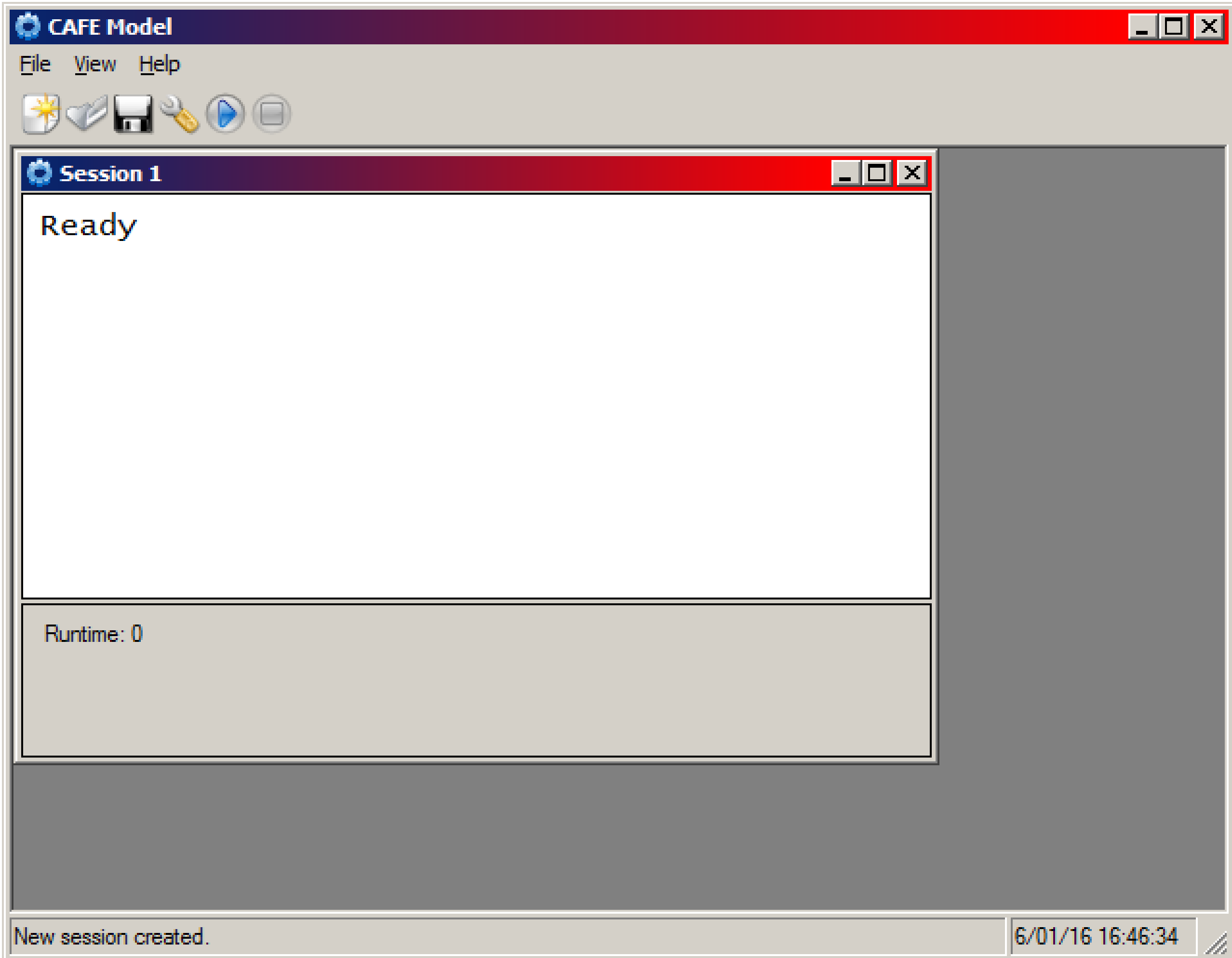

Figure 22. New Compliance Model Session Created

- Save the new session by selecting **File > Save Session As...**. Enter "demo.cmsd" in the dialog box that appears, and click the **Save** button (Figure 23).

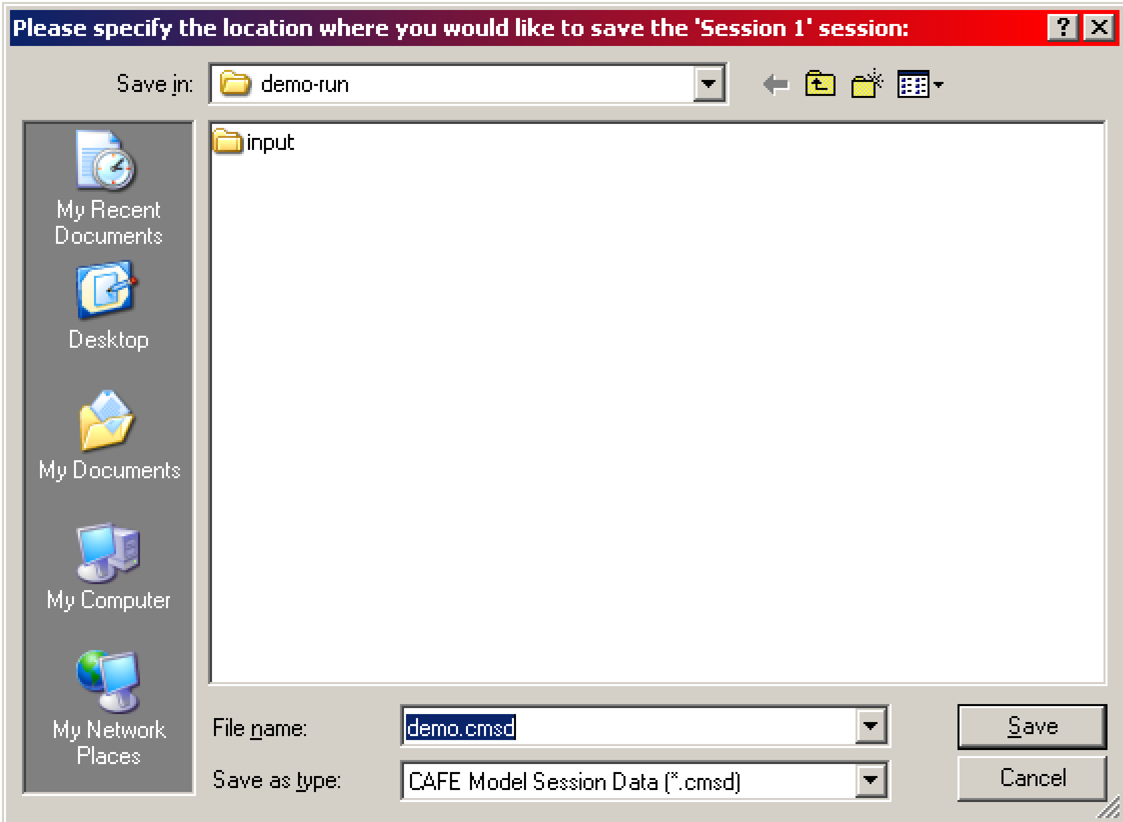

Figure 23. Save New Session

- After the session has been saved, notice the title of the session has changed to "demo" (Figure 24).

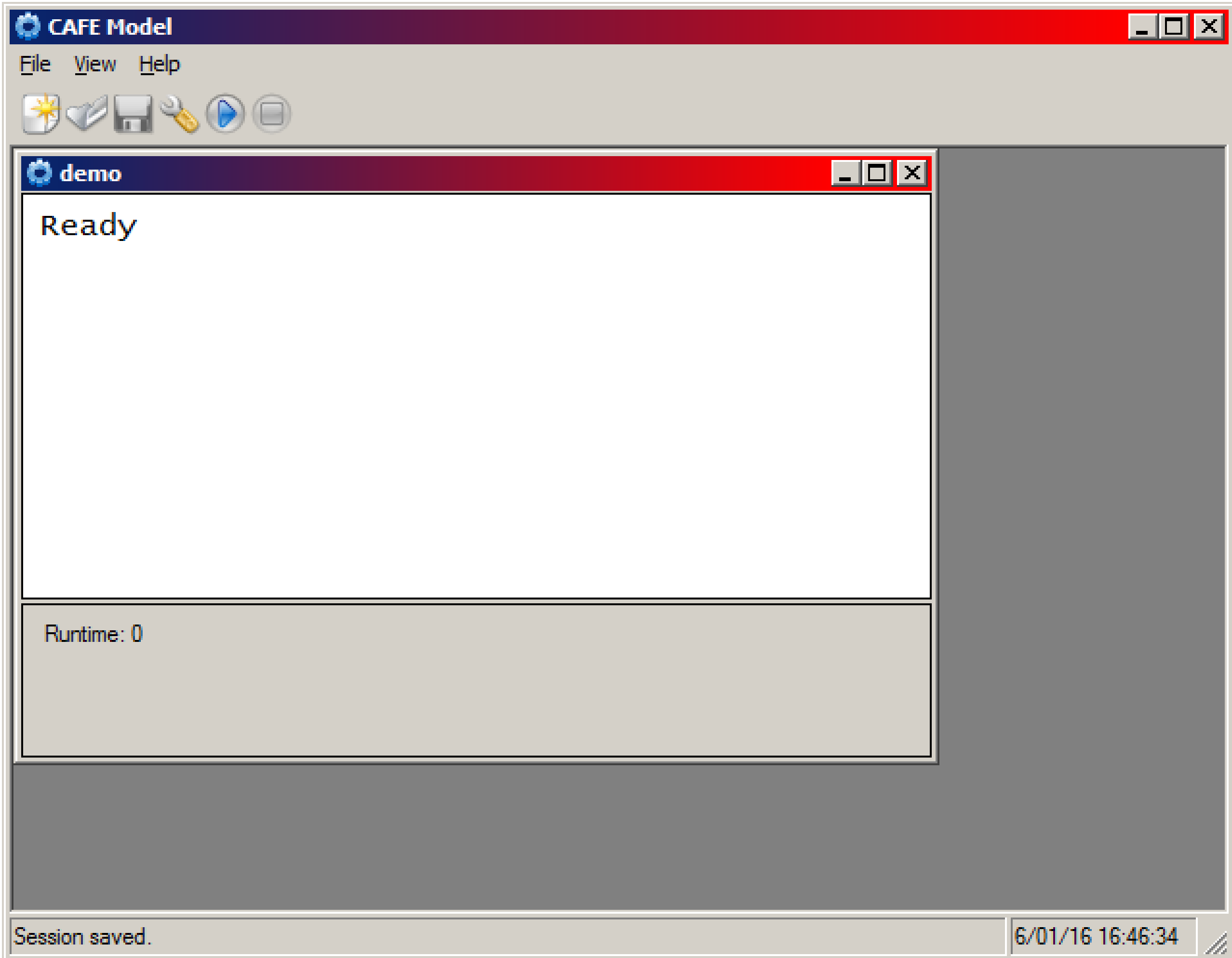

Figure 24. "demo" Session Saved

- Select **File > Start Modeling** to start the compliance modeling process. As the model runs, the progress of the *Compliance Model* is displayed in the session window (Figure 25).

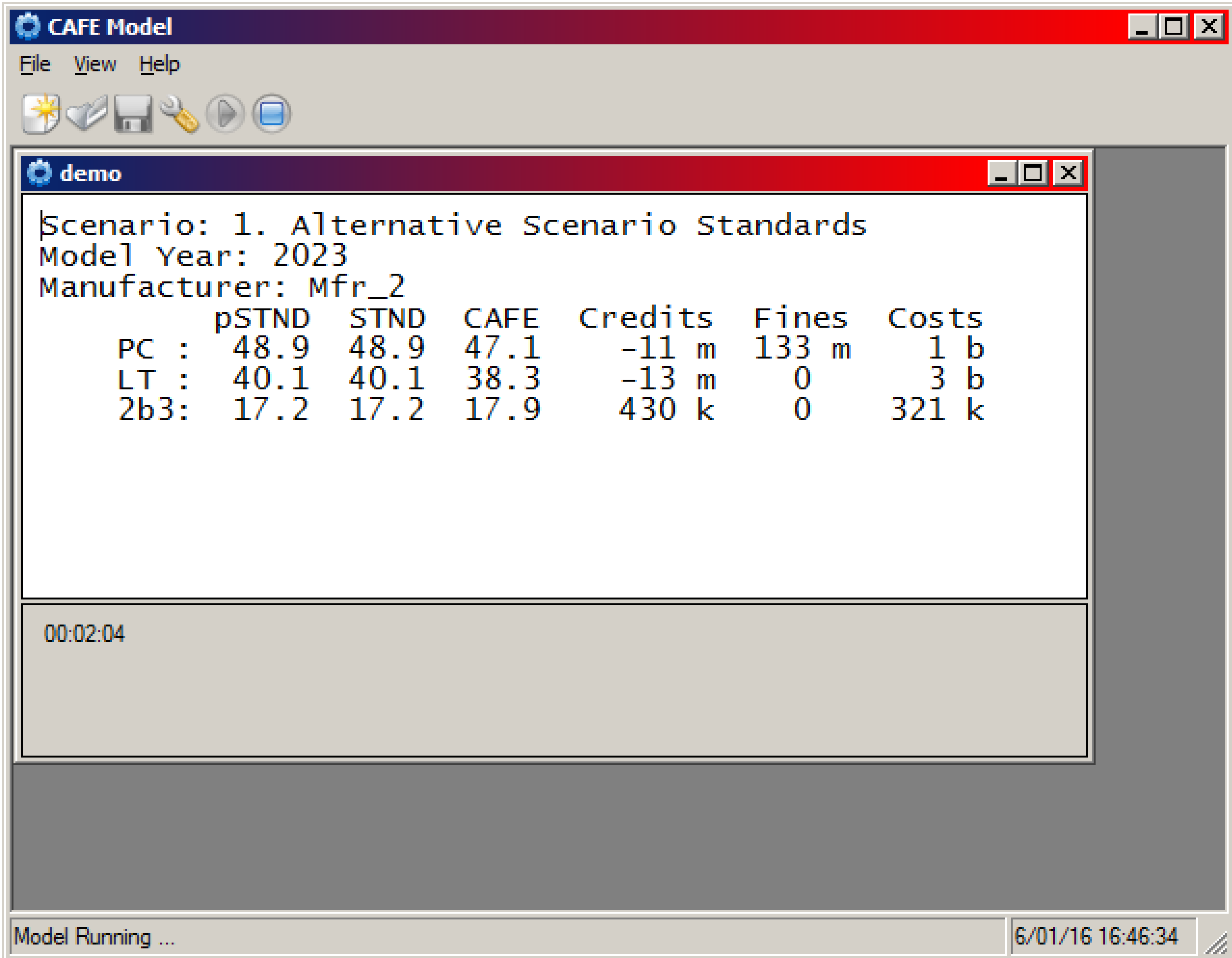

Figure 25. Modeling Progress from the Compliance Model

- After modeling has completed, the "Modeling Completed!" message appears at the bottom of the main **CAFE Model** window (Figure 26).

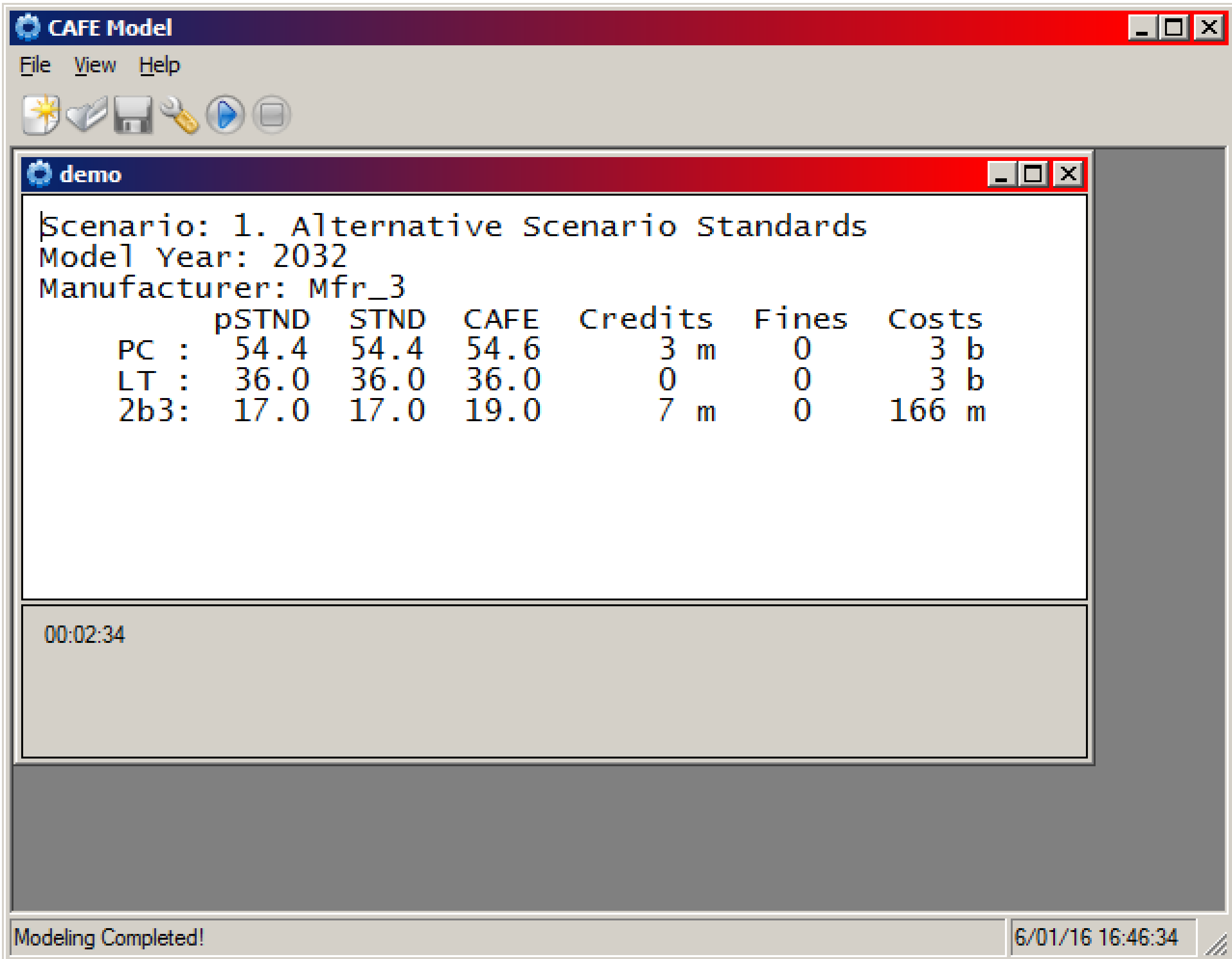

Figure 26. Compliance Model Completed

- Select **View** > **Output Location** to open Windows Explorer and browse to the location where model outputs for the "demo" session are saved.
- Exit the session by selecting **File > Close Session**.
- Exit the **CAFE Model** by selecting **File > Exit**, or proceed to the next example.

C.5.2 Example 2 – Configuring for "Fleet Analysis" Modeling

This example demonstrates how to take an existing session created in Example 1 – Configuring for Standard Compliance Modeling, and modify it to perform fleet analysis calculations.

- Run the CAFE Model by clicking on the **CAFE Model** executable located on the desktop. Read through the **Warnings** dialog box, and then click the **OK** button.
- Select **File** > **Open Session** to open an existing modeling session. Select "demo.cmsd" in the dialog box that appears, and click the **Open** button (Figure 27).

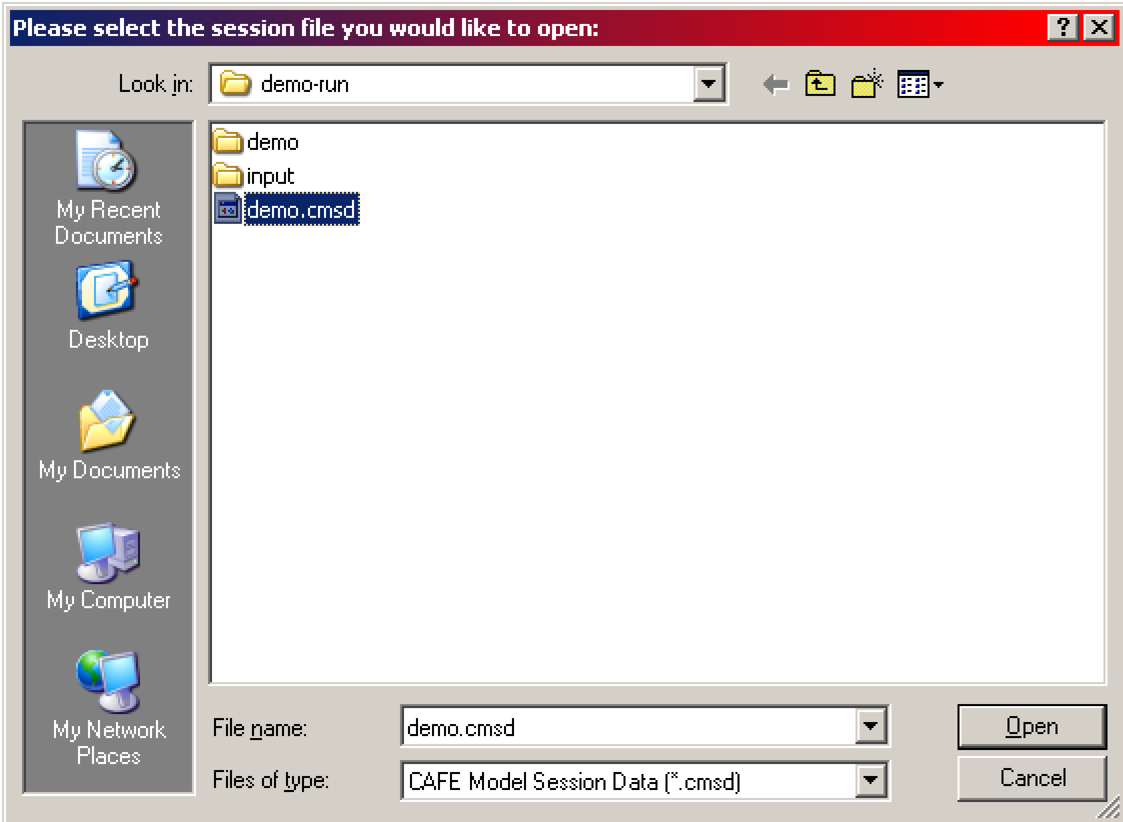

Figure 27. Open "demo" Session

- Once the session has been loaded, select **View > Modeling Settings** to bring up the **Modeling Settings** window.
- Click on the **Runtime Settings** panel and select the *Perform Fleet Analysis Calculations* option as in Figure 28.

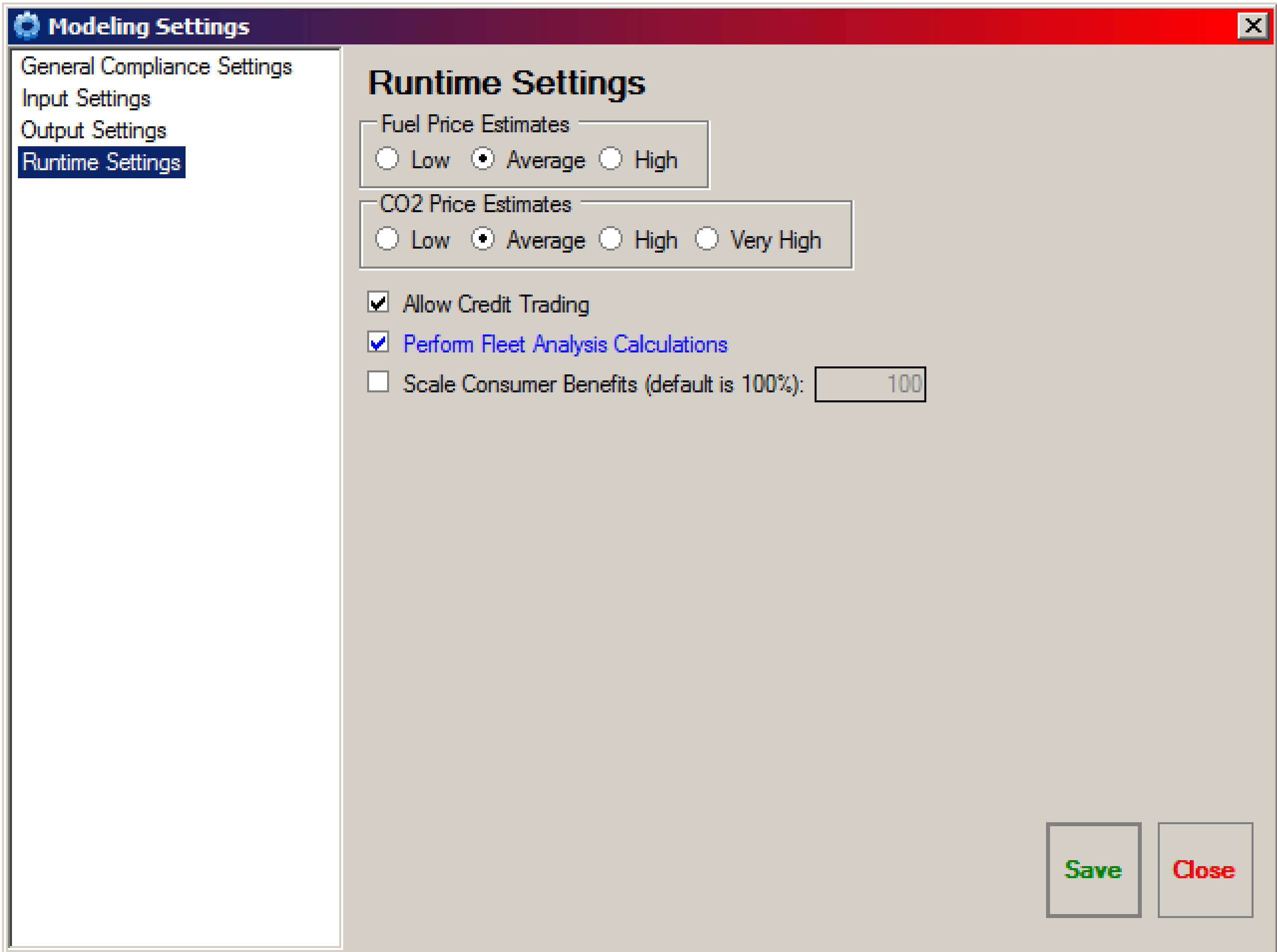

Figure 28. Enable Fleet Analysis Calculations

- The rest of the panels are not used for this exercise.
- Click the **Save** button to save the updated modeling settings; then click **Close**, once saving completes.
- To prevent overwriting results from the "demo" session, select **File > Save Session As...** to save the modified session with a new name. For this example, the session was saved as "demo-fleet-analysis.cmsd".
- Select **File > Start Modeling** to start the modeling process. As the model runs, the progress of the *Compliance Model* is displayed in the session window.
- After compliance and fleet analysis modeling has completed, the "Modeling Completed!" message appears at the bottom of the main **CAFE Model** window. Select **File > Exit** to exit the model.

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National Highway
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