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**CAFE Compliance and Effects Modeling System**

**Documentation (Draft, 7/19/05)**

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## 1 I. Introduction

2  
3 In December 1975, during the aftermath of the energy crisis created by the oil embargo of  
4 1973-1974, Congress enacted the Energy Policy and Conservation Act (EPCA). The Act  
5 established an automotive fuel economy regulatory program by adding Title V, "Improving  
6 Automotive Efficiency," to the Motor Vehicle Information and Cost Saving Act. These  
7 corporate average fuel economy (CAFE) standards set a minimum performance requirement in  
8 terms of an average number of miles a vehicle travels per gallon of gasoline or diesel fuel.  
9 Section 32902(a) of Chapter 329 states that the Secretary of Transportation shall prescribe by  
10 regulation CAFE standards for light trucks for each model year in consideration of four factors in  
11 determining the "maximum feasible" fuel economy level:

- 12
- 13 (1) technological feasibility;
- 14 (2) economic practicability;
- 15 (3) the effect of other Federal motor vehicle standards on fuel economy; and
- 16 (4) the need of the Nation to conserve energy.
- 17

18 CAFE standards are set by statute for passenger cars and by regulation for light trucks. The first  
19 light truck CAFE standards were established for model year (MY) 1979 and applied to light  
20 trucks with Gross Vehicle Weight Ratings (GVWR) up to 6000 pounds. Beginning with MY  
21 1980, NHTSA raised this GVWR ceiling to 8500 pounds. During the 1980's and early 1990's,  
22 light truck standards were set frequently, covering short time periods. In 1994, the agency  
23 departed from its usual past practice of considering light truck standards for one or two model  
24 years at a time and published an Advance Notice of Proposed Rulemaking (ANPRM) in the  
25 Federal Register outlining NHTSA's intention to set standards for some, or all, of MYs 1998-  
26 2006. On November 15, 1995, Congress put a freeze on all CAFE related activities in the  
27 Department of Transportation and Related Agencies Appropriations Act for FY 1996, stating:

28  
29 None of the funds in this Act shall be available to prepare, propose, or promulgate  
30 any regulations . . . prescribing corporate average fuel economy standards for  
31 automobiles . . . in any model year that differs from standards promulgated for  
32 such automobiles prior to enactment of this section.  
33

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

37  
38 The Department of Transportation and Related Agencies Appropriations Act for FY 2001  
39 contained the restriction on CAFE rulemaking identical to that contained in prior appropriation  
40 acts. However, the conference committee report for that Act directed that NHTSA fund a study  
41 by the National Academy of Sciences (NAS) to evaluate the effectiveness and impacts of CAFE  
42 standards. NAS submitted its report to the Department of Transportation on July 30, 2001. The  
43 final report, released in January 2002, concluded that technologies exist that could significantly  
44 increase passenger car and light truck fuel economy within 15 years.  
45

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

11  
12 After the MY 2005-2007 light truck rulemaking ended, it became apparent that the development  
13 of an automated rulemaking tool capable of evaluating both the stringency and changes in the  
14 structure of the CAFE regulation would be desirable for a number of reasons. In the past,  
15 standards have been set by manually applying fuel saving technologies to individual vehicles to  
16 determine a standard. While this process has its merits, it is time consuming and generally not  
17 repeatable. An automated modeling system would help meet tight the deadlines demanded by the  
18 rulemaking process. Presently, we are limited to setting standards for only a few years at a time.  
19 CAFE standards must be set no more than 18 months in advance of the regulated MY. For  
20 example, standards governing MY 2008 must be set no later than April 1, 2006. If a standard is  
21 not set for a given MY, there is no CAFE standard for the year. The process begins at least a year  
22 earlier with a 90-day request for comment (RFC) and solicitation of manufacturer product plans.  
23 Once the data is analyzed, standards are proposed in a notice of proposed rulemaking (NPRM)  
24 followed by a 90-day comment period. Comments are analyzed and incorporated into the  
25 analysis to determine if there is a need to modify the proposed standards for the final rule.

26  
27 Although the entire process takes a year or longer, the time allowed for analysis is much shorter.  
28 Initial standards must be determined after the RFC comment period has closed and before the  
29 NPRM is released. Final standards are determined after the NPRM comment period closes and  
30 before the FR is published. A computerized rulemaking analysis system would save time during  
31 the two short periods that the agency has to determine CAFE standards. Keeping the system  
32 updated in periods in between rulemakings would alleviate the need to "reinvent the wheel"  
33 every one, two or three years that CAFE standards must be set.

34  
35 CAFE activities involve more than setting light truck stringency standards. The agency is  
36 frequently asked by Congress and the administration to evaluate alternative CAFE proposals that  
37 are considered in legislation. These requests must be answered within a few days. The agency is  
38 also involved in a rulemaking to reform the regulation. On December 29, 2003, NHTSA  
39 published an advanced notice of proposed rulemaking (ANPR) for CAFE reform. In the  
40 document, we describe potential reforms that we have the statutory authority to implement.  
41 Many of these reforms were suggested in the NAS report. In the past year, NHTSA had to  
42 evaluate a petition filed by Nissan of North America. All of these tasks will or would be greatly  
43 simplified by an automated rulemaking analysis system.

44  
45 Over time, the analysis required to set CAFE standards has become increasingly complicated and  
46 presently includes a multitude of economic and environmental impacts that were not considered

1 in the past. In addition to accounting for these impacts, a computer model will allow for the  
2 evaluation of incremental costs and benefits rather than total costs and benefits when setting  
3 standards. The model will also allow for an uncertainty analysis to measure the potential range of  
4 outcomes. Neither of these types of analyses are practical under the manual approach of applying  
5 technologies to each vehicle.

6  
7 The CAFE rulemaking analysis system that is described in this document links all the analyses  
8 together into a cohesive and transparent computer model. The model can be used to analyze  
9 changes in CAFE stringency and the structure of the regulation separately or simultaneously over  
10 several model years. Given a policy change, the modeling system predicts how manufacturers  
11 will react through applications of fuel saving technologies to comply with CAFE standards. The  
12 system then determines the economic and environmental impacts that result.

13  
14 When constructing the modeling system, we relied on well-known studies, models and  
15 assumptions from credible sources outside the Department of Transportation. Technology  
16 assumptions and implementation paths are taken from the National Academy of Science's CAFE  
17 report. Economic assumptions come from various academic publications and the Office of  
18 Management and Budget's regulatory guidelines. Environmental analyses are conducted using  
19 the Environmental Protection Agency's MOBILE6 model and Argonne National Laboratory's  
20 GREET model.

## 21 22 **II. Comparability to Other Modeling Systems**

23  
24 Before beginning development of this modeling system, we considered other options for  
25 analyzing CAFE standards. However, such options are limited by structural and functional  
26 considerations. The most important structural requirement is the ability to represent the vehicle  
27 fleet in fine detail. Specifically, each vehicle model configuration, of which there are more than  
28 a thousand, must be accounted for separately. Important functional requirements include, but are  
29 not limited to the ability to properly account for various combinations of potential CAFE  
30 reforms, determine the applicability and cost efficiency of various technologies on a model-by-  
31 model basis, account for the use of a given engine or transmission across multiple vehicle  
32 models, calculate shifts in sales volumes resulting from changes in vehicle prices and fuel  
33 economy levels, properly assign vehicle models to relevant emissions "classes", and calculate  
34 changes in highway travel, energy demand, emissions, and economic externalities related to  
35 highway travel and energy consumption.

36  
37 Although various other modeling systems address some of these requirements, and some do so  
38 more robustly than the system discussed here, we are aware of no other system that provides the  
39 ability to efficiently fulfill even a majority of these requirements.

40  
41 The most relevant alternative modeling system known to us is the National Energy Modeling  
42 System (NEMS), which is maintained by the Department of Energy's (DOE's) Energy  
43 Information Agency (EIA).<sup>1</sup> NEMS is an integrated modeling system designed to forecast future  
44 energy supply and demand based on a wide range of data and assumptions regarding key supply

---

<sup>1</sup> NEMS documentation is available at <http://www.eia.doe.gov/bookshelf/docs.html>.

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

9  
 10 We expect to use NEMS to develop some key inputs, such as fuel prices and domestic refinery  
 11 output, for the system discussed here. Separately, because our system does not attempt to  
 12 simulate energy supply, we also expect to use NEMS to examine potential feedbacks between  
 13 CAFE policies and energy markets (although such feedbacks are typically estimated to be  
 14 relatively small).

15  
 16 **Table 1. Key Differences between this System and NEMS**

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

18  
 19 However, the ability of NEMS to meet the above-mentioned requirements is currently limited in  
 20 several important ways, as is understandable given that NEMS is designed primarily for mid-  
 21 term energy forecasting, not near-term regulatory analysis. Key differences, summarized above  
 22 in Table 1, are as follows: First, and most important, although NEMS divides light vehicles into  
 23 several representative classes, it cannot represent light vehicles on a model-by-model basis. This  
 24 means, that NEMS does not produce manufacturer-specific estimates of compliance costs.  
 25 Second, although NEMS allows for the year-by-year specification of standards for passenger and  
 26 nonpassenger CAFE standards, it does not provide the ability to simulate most potential CAFE

1 reforms. Because of its class-based representation of the vehicle market, modification of NEMS  
2 to represent many CAFE reforms would require significant data development and programming.  
3

4 Among other modeling systems we have considered, key capabilities and limitations vis-à-vis  
5 analysis to support CAFE rulemakings are as follows:  
6

7 ADVISOR: The “Advanced Vehicle Simulator” (ADVISOR), which was created by  
8 DOE’s National Renewable Energy Laboratory (NREL) and recently commercialized by  
9 AVL Powertrain Engineering, estimates vehicular energy consumption through second-  
10 by-second simulation based on detailed vehicle and drive cycle characteristics.<sup>2</sup> Though  
11 possibly relevant in a vehicle design environment, ADVISOR’s data requirements are far  
12 too extensive for CAFE analysis, and it provides no means of performing most other  
13 CAFE-related calculations (e.g., compliance evaluation, cost estimation, fleet energy  
14 consumption and emissions). Similar vehicle simulation tools, such as AVL’s CRUISE  
15 model and Argonne’s PSAT model, share these basic capabilities and limitations.  
16

17 GREET: Argonne’s “Greenhouse Gases, Regulated Emissions, and Energy Use in  
18 Transportation” (GREET) model is a spreadsheet-based system that estimates full fuel-  
19 cycle energy consumption and emissions for various combinations of vehicle  
20 technologies and fuels.<sup>3</sup> Although GREET does not perform other CAFE-related  
21 calculations (e.g., cost estimation), we use it to estimate upstream (i.e., non-vehicular)  
22 emissions as inputs to our modeling system.  
23

24 MOBILE: EPA’s MOBILE model predicts vehicular emission rates under various  
25 conditions.<sup>4</sup> Although MOBILE does not perform other CAFE-related calculations, we  
26 use it to estimate vehicular emissions as inputs to our modeling system.  
27

28 SGM: Pacific Northwest National Laboratory’s (PNNL’s) “Second Generation Model”  
29 (SGM), developed as a complement to the PNNL’s first generation model (“MiniCAM”),  
30 is a computable general equilibrium model with conceptual similarities to NEMS and  
31 explicit representation of transportation sector energy demand. However, the SGM does  
32 not explicitly represent CAFE standards, and its representation of the passenger vehicle  
33 market is far too generalized to be meaningful for CAFE-related analysis.<sup>5</sup>  
34

35 TAFV: Leiby and Rubin’s “Transitional Alternative Fuels and Vehicles” (TAFV) model  
36 estimates the cost and consumption of alternative fuels and alternative fuel vehicles  
37 during a transition between a conventional market and a market in which such fuels and  
38 vehicles play a much more significant role.<sup>6</sup>

---

<sup>2</sup> Documentation of ADVISOR is available at <http://www.ctts.nrel.gov/analysis/advisor.html>.

<sup>3</sup> Documentation of GREET is available at <http://www.transportation.anl.gov/software/GREET/index.html>.

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

<sup>5</sup> Documentation of SGM and MiniCAM is available at <http://www.globalchange.umd.edu/?tools>.

<sup>6</sup> Documentation of TAFV is available at <http://pzll.ed.ornl.gov/altfuels.htm>.



### III. Design and Rationale

#### A. Overall Structure

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

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

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

---

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

1 Different categorization schemes are relevant to different types of effects. For example, while  
2 energy and carbon dioxide calculations group vehicles by type of fuel, criteria pollutant  
3 calculations group vehicles by U.S. Environmental Protection Agency (EPA) emissions classes.  
4 Therefore, unlike many other modeling systems, this system uses model-by-model categorization  
5 and accounting when calculating most effects, and aggregates results only as required for  
6 efficient reporting.  
7

## 1 B. CAFE Compliance Simulation

### 3 B.1. Compliance Simulation Algorithm

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

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

#### 30 *Initial State of the Fleet*

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

Vehicle Models Worksheet

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

Engines Worksheet

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

Transmissions Worksheet

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

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

1  
2  
3  
4

1 *Technology Application*

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

15  
16 **Table 2. Technologies**

17

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

18  
19 As discussed in Appendix C, input assumptions for each of these technologies are specified in  
20 the technologies input file, and are specific to each of the following vehicle types: small SUVs,  
21 midsize SUVs, large SUVs, minivans, small pickups, large pickups, subcompact cars, compact  
22 cars, midsize cars, and large cars. Table 3 lists the input assumptions specified in this file.

<sup>8</sup> [add reference]

<sup>9</sup> Replacing a gasoline engine with a Diesel engine.

<sup>10</sup> Aerodynamic improvements have been assigned to a separate technology group.

<sup>11</sup> Increasing vehicle weight through materials substitution.

Table 3. Technology Input Assumptions

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

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

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

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

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

1 The algorithm next determines the applicability of each technology to each vehicle model,  
2 engine, and transmission. If the technology is available in the current model year and included  
3 on the NAS technology application path selected by the user (*e.g.*, if the user has selected "Path  
4 2" and Path2 is set to "TRUE" for the appropriate vehicle type and the technology in question),  
5 the system identifies the technology as potentially applicable. However, technology "overrides"  
6 can be specified for specific vehicle models, engines, and transmissions in the corresponding  
7 input files.<sup>14</sup> If any such overrides have been specified, the algorithm reevaluates applicability as  
8 shown in Figure 2.

9

---

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

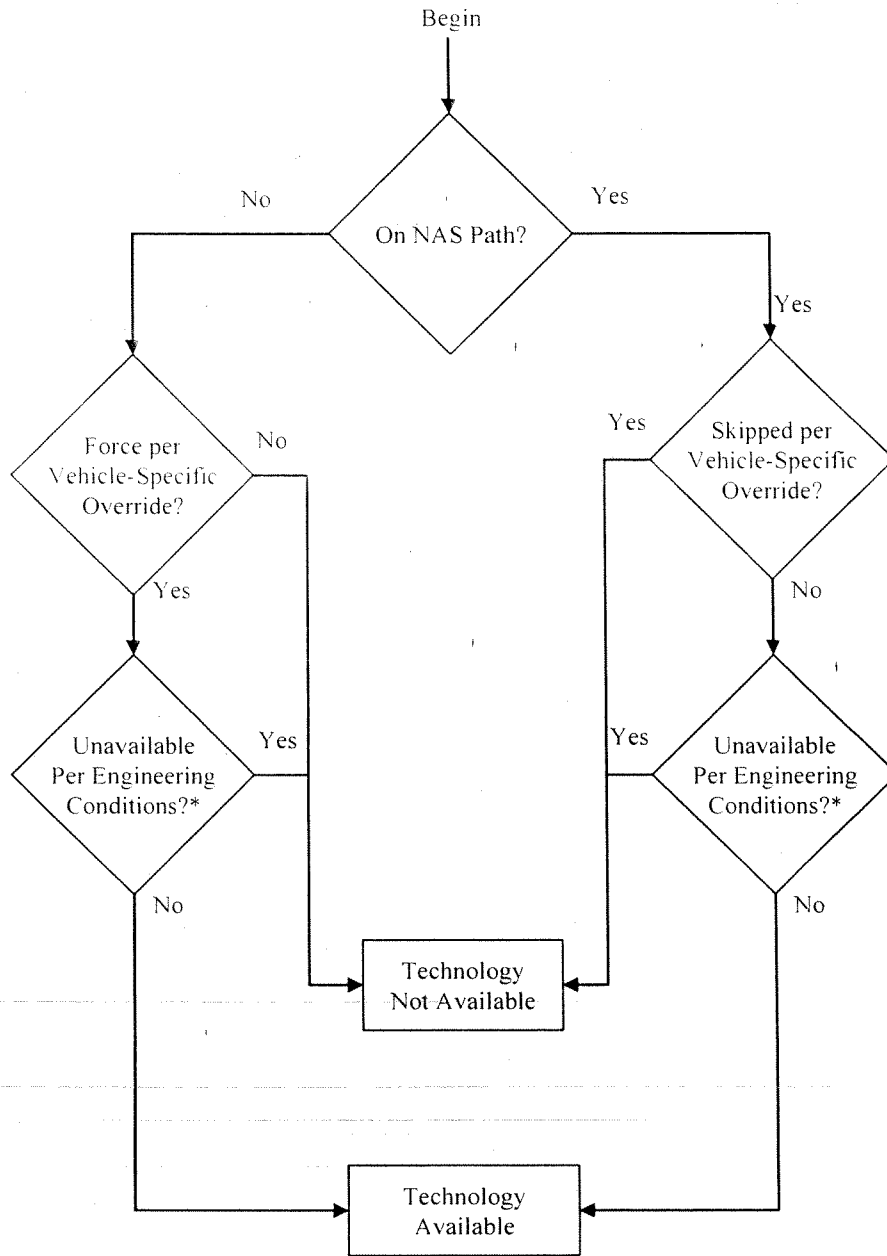


Figure 2. Technology Applicability Determination

1  
2  
3  
4



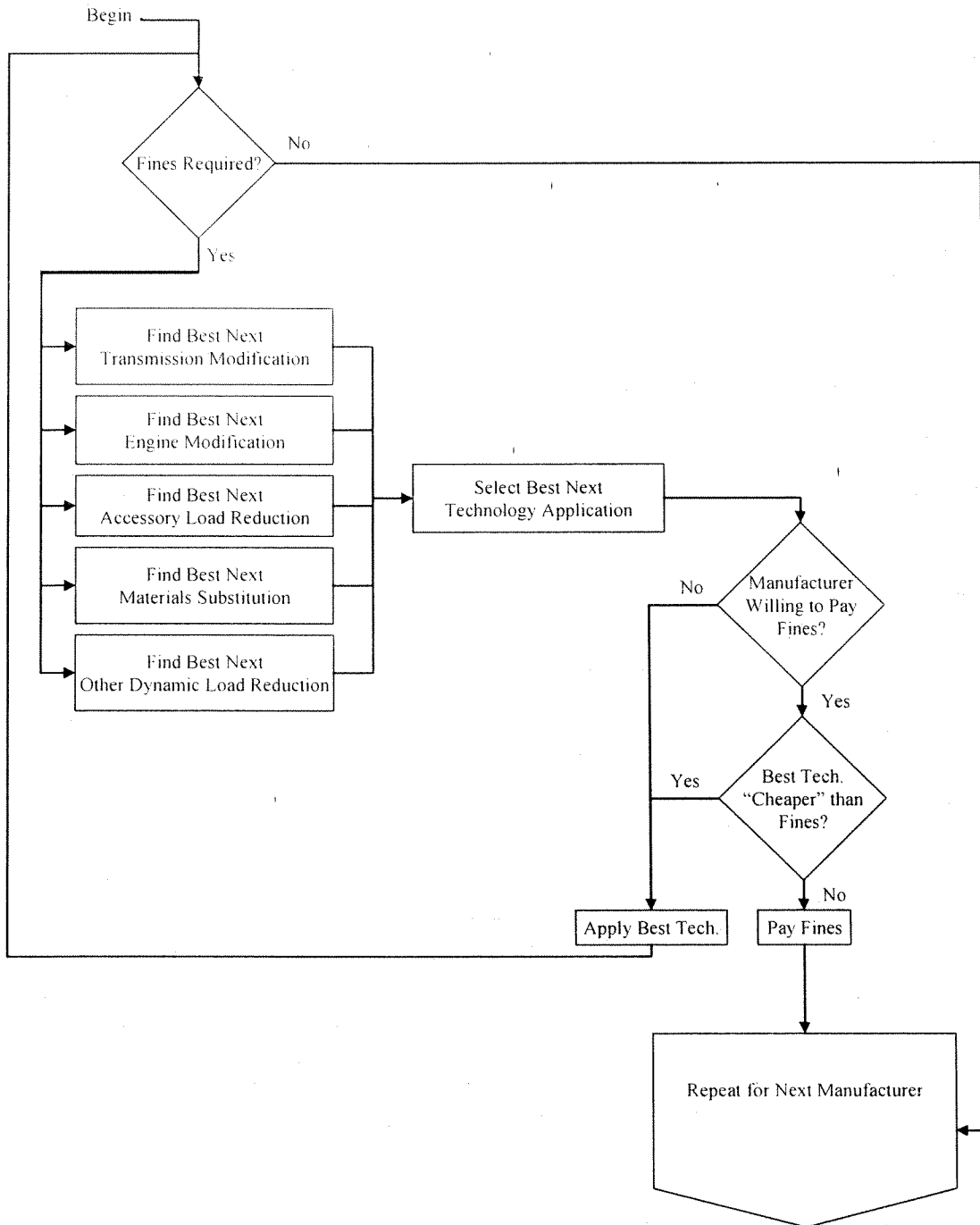
1 If a given technology is still considered applicable after considering any overrides, the algorithm  
 2 again reevaluates applicability based the following engineering conditions:

3  
 4 **Table 4. Engineering Conditions for Technology Applicability**  
 5

#	Condition
1	If engine oil less viscous than 10W30, assume low friction lubricants not applicable.
2	If more than two valves per cylinder, assume multivalve OHC not applicable.
3	If valve timing not fixed, assume VVT and cylinder deactivation not applicable.
4	If valve lift not fixed, assume VVLT and cylinder deactivation not applicable.
5	If valve lift continuously variable but valvetrain design not camless, assume intake valve throttling not applicable.
6	If valvetrain design camless, assume camless valve actuation not applicable.
7	If amount of cylinder deactivation greater than zero, assume cylinder deactivation not applicable.
8	If fewer than six cylinders, assume cylinder deactivation not applicable.
9	If aspiration turbocharged or supercharged, assume supercharging and downsizing not applicable.
10	If min and max compression differ, assume variable compression ratio not applicable.
11	If Diesel cycle, assume following engine technologies not applicable: multivalve OHC, VVT, VVLT, supercharging and downsizing, cylinder deactivation, intake valve throttling, camless valve actuation, variable compression ratio, and Dieselization.
12	If automatic transmission with more than four gears, assume five-speed transmission not applicable.
13	If automatic transmission with more than five gears, assume five-speed transmission, six-speed transmission, CVT, and advanced CVT not applicable.
14	If CVT, assume all transmission technologies except HEV not applicable.
15	If manual transmission, assume all transmission technologies except automatically-shifted manual and HEV not applicable.
16	If rear-wheel drive or four-wheel drive pickup or SUV, assume improved rolling resistance not applicable.
17	If HEV, assume 42V electrical system, ISG, and midrange HEV not applicable.

6  
 7 Having determined the applicability of each technology to each vehicle model, engine, and/or  
 8 transmission, the compliance simulation algorithm begins the process of applying technologies  
 9 based on the CAFE standards applicable during the current model year. This involves repeatedly  
 10 evaluating the degree of noncompliance, identifying the “best next” technology available on each  
 11 of the parallel technology paths mentioned above, and applying the best of these. Figure 3 gives  
 12 an overview of the process. If, considering all regulatory classes, the manufacturer owes no  
 13 CAFE fines, the algorithm applies no technologies beyond any carried over from the previous  
 14 model year. If the manufacturer does owe CAFE fines, the algorithm first finds the best next  
 15 applicable technology in each of the technology groups (*e.g.*, engine technologies), and applies  
 16 the same criterion to select the best among these. If this manufacturer is assumed to be unwilling  
 17 to pay CAFE fines (or, equivalently, if the user has set the system to exclude the possibility of  
 18 paying fines as long as some technology can still be applied), the algorithm applies the  
 19 technology to the affected vehicles. If the manufacturer is assumed to be willing to pay CAFE  
 20 fines and applying this technology would have a lower “effective cost” (discussed below) than  
 21 simply paying fines, the algorithm also applies the technology. In either case, the algorithm then  
 22 reevaluates the manufacturer’s degree of noncompliance. If, however, the manufacturer is  
 23 assumed to be willing to pay CAFE fines and doing so would be less expensive than applying the

1 best next technology, the algorithm stops applying technology to this manufacturer's products.  
2 After this process is repeated for each manufacturer, the compliance simulation algorithm  
3 concludes.  
4



5  
6  
7  
8

Figure 3. Compliance Simulation Algorithm

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

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

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

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

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

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

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

<sup>16</sup> 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.

<sup>17</sup> Exceptions can occur if materials substitution is applied under a weight-based system.

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

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

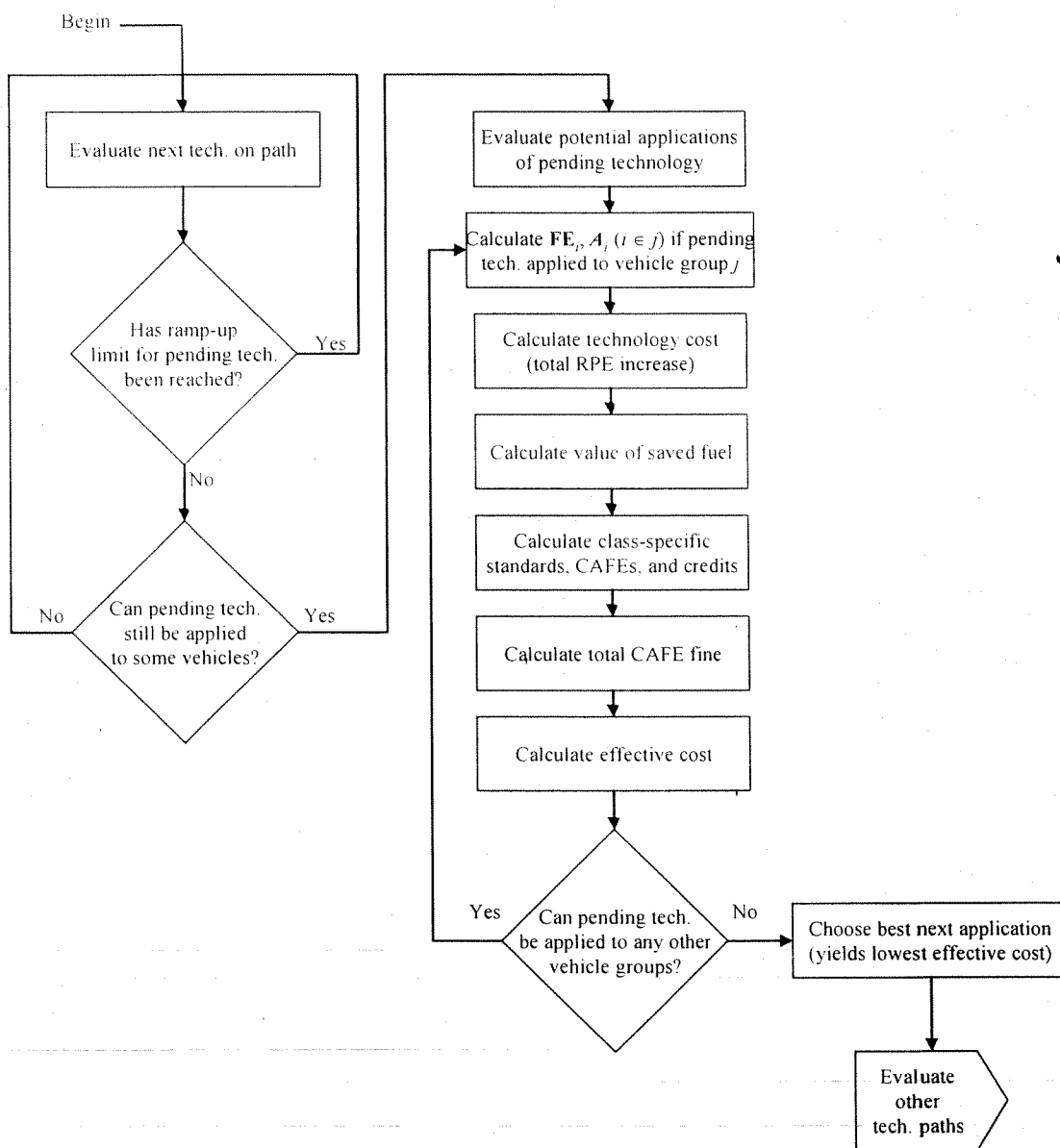
Within each regulatory class  $C$ , the net amount of CAFE credit created (noncompliance causes credit creation to be negative, which implies the use of CAFE credits) is calculated by subtracting the CAFE level achieved by the class from the standard applicable to the class, and multiplying the result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

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

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

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

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



1  
2  
3

Figure 4. Determination of "Best Next" Technology Application

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

### 8 9 **C. Calculation of Effects**

10  
11 This section describes how the effects of tightening or reforming CAFE standards on energy use,  
12 emissions of air pollutants and greenhouse gases are estimated. These effects are caused by  
13 improvements in the fuel economy of some vehicle models as manufacturers respond to changes  
14 in the CAFE standards, together with changes in the composition and use of the light-duty  
15 vehicle fleet resulting from new vehicle buyers' responses to changes in the prices and fuel  
16 economy levels of new vehicle models. This section also describes how these various impacts  
17 are translated into estimates of economic benefits or costs, and identifies whether these economic  
18 impacts are borne privately by vehicle owners or by society as a whole.

19  
20 The effects on energy use, emissions from tightening or reforming CAFE standards are estimated  
21 separately for each individual vehicle model and vintage (model year) over its expected life span  
22 in the U.S. vehicle fleet.<sup>28</sup> A vehicle's life span extends from the initial year when it is produced  
23 and sold until the time when all vehicles from that model year have been scrapped or retired

---

<sup>28</sup> [deleted]

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

6  
 7 Although these effects are calculated for individual vehicle models and vintages, they are  
 8 typically reported at the aggregate level for all vehicle models in each CAFE class (domestic,  
 9 automobiles, import automobiles, and light trucks) produced during each model year affected by  
 10 the stricter standard. These aggregated values are reported for each future calendar year during  
 11 which a model year remains in the vehicle fleet. Cumulative impacts for each CAFE class and  
 12 model year over its expected life span are also reported, both in undiscounted terms and as their  
 13 present value discounted to the calendar year when each model year is offered for sale.<sup>31</sup>

#### 14 15 *Light-Duty Vehicle Sales and Fleet*

16  
 17 The forecast number of new vehicles of a specific model  $k$  sold during a given model year  $MY$  is:

$$18 \quad n_{k,MY} = N_{MY} P_{k,MY} \quad (1.13)$$

19  
 20 Where  $N_{MY}$  indicates the forecast of total new light-duty vehicle sales during that model year,  
 21 and the forecast market share of each vehicle model produced during that year,  $P_{k,MY}$ , is obtained  
 22 from (1.6), (1.7), and (1.8), as discussed previously in Section III.B.<sup>32</sup>

23  
 24 The number of vehicles of a specific model and vintage that remains in service during each  
 25 subsequent calendar year is calculated by applying estimates of the proportion of vehicles  
 26 initially sold that remain in service at each age. Thus the number of vehicles of model  $k$   
 27 produced during model year  $m$  that remain in use during a future year  $t$ , or  $n_{k,MY,t}$ , is:

$$28 \quad n_{k,MY,t} = n_{k,MY} s_{k,t} \quad (1.14)$$

29  
 30 where  $s_{k,t}$  denotes the proportion of vehicles of model  $k$  expected to remain in use during year  $t$ .  
 31 During year  $t$ , those vehicles will have reached age  $a$ , where  $a = t - MY + 1$ .<sup>33</sup> The model  
 32 utilizes different schedules of expected survival rates by vehicle age for six separate classes of  
 33  
 34

<sup>29</sup> We adopt the simplification that vehicle model years and calendar years are identical.

<sup>31</sup> [deleted]

<sup>32</sup> The subscripts denoting buyers ( $n$ ) and the market segment ( $s$ ) that includes vehicle model  $k$  are dropped to simplify this and the following expressions.

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

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

### 3 4 **C.1. Vehicle Use and Total Mileage**

5  
6 The total number of miles driven by vehicles of a specific model and vintage (or model year)  
7 during each year they remain in the fleet is calculated by multiplying age-specific estimates of  
8 annual miles driven per vehicle by the number of vehicles of that model year remaining in  
9 service at the age corresponding to that future year. As with survival rates, the average number  
10 of miles driven by a specific vehicle model at each age during its expected lifetime differs  
11 depending on its vehicle class. Thus the total miles driven by vehicles of model  $k$  produced  
12 during model year  $MY$  that are expected to remain on the road during year  $t$ , denoted  $M_{k,MY,t}$  is  
13 calculated as:

$$14 \quad M_{k,MY,t} = n_{k,MY,t} m_{k,MY,t} \quad (1.15)$$

15  
16 where  $m_{k,MY,t}$  is the average number of miles that a surviving vehicle of model  $k$  is driven during  
17 year  $t$ , when those vehicles will have reached age  $a = t - MY + 1$ . The model uses separate  
18 estimates of average annual utilization at different ages for different classes of light-duty  
19 vehicles, as discussed in Appendix C. As with survival rates, we assume that annual usage of  
20 each vehicle type at each age during its expected lifetime will remain unchanged for future  
21 model years.  
22

23  
24 Separate estimates of average annual utilization at different ages are used for automobiles and  
25 several different classes of light-duty trucks, as discussed in Appendix C.

#### 26 27 *Accounting for the "Rebound Effect"*

28  
29 Improving a vehicle's fuel economy reduces the cost of driving by reducing the amount of fuel  
30 required to drive each mile. In response to the lower per-mile cost of driving a more fuel-  
31 efficient vehicle, some buyers will increase the amount of driving they do, although the precise  
32 nature and magnitude of this response is uncertain. Thus imposing stricter fuel economy  
33 standards results in a slight increase in the annual number of miles driven by vehicle models  
34 whose fuel economy is improved as a result of manufacturers' efforts to comply with those  
35 standards.<sup>34</sup> This increase in the annual use of vehicle models whose fuel economy is improved,  
36 referred to as the "rebound effect" in vehicle use, results in a corresponding increase in the total  
37 number of miles driven by vehicles produced during each model year affected by the stricter  
38 standards during each year they remain in the fleet.

39  
40 The proportional increase in the average annual number of miles driven during year  $t$  by a  
41 vehicle model  $k$  when its fuel economy is improved from the level specified by its  
42 manufacturer's product plan for its model year, denoted  $mpg_{k,MY,plan}$ , to a higher level,

---

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



1  $mpg_{k,MY,t,CAFE}$ . is calculated using a standard form for the elasticity of travel demand with respect  
 2 to the fuel cost of driving:  
 3

$$4 \quad \frac{\Delta m_{k,MY,t,CAFE}}{m_{k,MY,t}} = \varepsilon_{cpm} \left[ \frac{\frac{f_t}{mpg_{k,CAFE}} - \frac{f_t}{mpg_{k,plan}}}{\frac{f_t}{mpg_{k,plan}}} \right] \quad (1.16)$$

5  
 6 where  $\varepsilon_{cpm}$  is the elasticity of vehicle use with respect to the cost of fuel per mile driven, a  
 7 measure of the rebound effect, and  $f_t$  is the price of fuel per gallon during future year  $t$ . Because  
 8 the fuel cost per mile driven by any vehicle is equal to the price of fuel per gallon divided by its  
 9 fuel economy in miles per gallon, the bracketed term in (1.16) represents the proportional  
 10 reduction in fuel cost per mile driven resulting from the improvement in fuel economy.<sup>35</sup>  
 11

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

$$14 \quad \Delta m_{k,MY,t,CAFE} = \varepsilon_{cpm} \left( \frac{mpg_{k,MY,t,plan}}{mpg_{k,MY,t,CAFE}} - 1 \right) m_{k,MY,t} \quad (1.17)$$

15  
 16 Finally, the increase in the total number of miles driven by vehicles of model  $k$  and model year  
 17  $MY$  each future year  $t$  they remain in the fleet, denoted  $\Delta M_{k,MY,t,CAFE}$  is calculated from:

$$18 \quad \Delta M_{k,MY,t,CAFE} = n_{k,MY,t} \Delta m_{k,MY,t,CAFE} \quad (1.18)$$

19  
 20 where  $n_{k,MY,t}$  is given by (1.14).  
 21

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

27  
 28 The existence of the rebound effect also means that any scenario requiring a vehicle  
 29 manufacturer to increase the fuel economy of some models from those indicated in its product  
 30 plan for that model year results in an increase in their use over each year of their expected  
 31 lifetime. Thus where a manufacturer's product plan specifies fuel economy levels that will result  
 32 in non-compliance with the CAFE standard in effect during the previous model year, any  
 33 improvement in the fuel economy of its models necessary to ensure compliance with that  
 34 baseline standard will produce a slight increase in their lifetime use through the rebound effect.  
 35

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

1 The effect on total annual mileage driven resulting from substituting a new CAFE standard  
 2 (denoted  $CAFE_1$ ) for a previous standard ( $CAFE_0$ ) is the difference in the added driving from the  
 3 rebound effects associated with the two standards:  
 4

$$5 \quad \Delta M_{k,a,t,CAFE1} - \Delta M_{k,a,t,CAFE0} = n_{k,a,t} (\Delta m_{k,a,t,CAFE1} - \Delta m_{k,a,t,CAFE0}) \quad (1.19)$$

## 6 C.2. Fuel Use and Savings

7  
 8  
 9 Fuel consumption by vehicles of each specific model and vintage during a future year depends  
 10 on the total mileage that the surviving vehicles are driven during that year, and the average fuel  
 11 efficiency they obtain in actual driving. Computing this value is complicated by the presence of  
 12 the rebound effect, which as discussed previously causes slightly higher annual usage throughout  
 13 the lifetime of any vehicle model whose fuel economy is improved above the level specified in  
 14 its manufacturer's product plan.  
 15

16 Another complication is posed by the difference between the fuel economy levels of new  
 17 vehicles as measured for purposes of assessing CAFE compliance and the (lower) levels they  
 18 actually achieve in real-world driving. Finally, it is also necessary to calculate fuel use  
 19 separately for gasoline and diesel vehicles, since these fuels result in different levels of  
 20 greenhouse gas and air pollutant emissions.  
 21

22 The number of gallons of fuel consumed by vehicles of model  $k$  and model year  $MY$  during year  
 23  $t$ , denoted  $g_{k,MY,t}$ , is calculated from:  
 24

$$25 \quad g_{k,MY,t} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY} (1 - gap)} \quad (1.20)$$

26  
 27 where  $gap$  indicates the difference between that model's fuel economy as measured for CAFE  
 28 purposes and its actual on-road fuel economy. We assume that a vehicle's fuel economy is  
 29 constant with respect to both age and accumulated mileage, and that the test versus on-road fuel  
 30 economy gap is identical for all vehicle types and ages.<sup>36</sup>  
 31

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

$$35 \quad g_{k,MY,t,plan} = \frac{M_{k,MY,t}}{mpg_{k,MY,plan} (1 - gap)} \quad (1.21)$$

36  


---

<sup>36</sup> These assumptions explain the absence of an age subscript on  $mpg$ , and of all subscripts on the parameter  $gap$ .

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

$$4 \quad g_{k,MY,t,CAFE} = \frac{M_{k,MY,t} + \Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} \quad (1.22)$$

6 or, equivalently:

$$8 \quad g_{k,MY,t,CAFE} = \frac{M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} + \frac{\Delta M_{k,MY,t}}{mpg_{k,MY,CAFE}(1-gap)} \quad (1.23)$$

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

$$16 \quad G_{t,CAFEt} = \sum_{MY} \sum_k (g_{k,MY,t,CAFEt} - g_{k,MY,t,CAFE0}) \quad (1.24)$$

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

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

$$26 \quad G_{MY,CAFEt} = \sum_t \sum_k (g_{k,MY,t,CAFEt} - g_{k,MY,t,CAFE0}) \quad (1.25)$$

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

$$31 \quad PV(G_{MY,CAFEt}) = \sum_t \sum_k \left( \frac{g_{k,MY,t,CAFEt} - g_{k,MY,t,CAFE0}}{(1+d)^{t-MY}} \right) \quad (1.26)$$

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

### 34 *Greenhouse Gas Emissions*

35 Environmental impacts from petroleum use stem primarily from combustion of petroleum  
 36 products such as gasoline, and to a lesser extent from petroleum refining and the distribution and  
 37 storage of refined products. These impacts include emissions of greenhouse gases, which are  
 38 widely believed to increase the potential for global climate change, and of regulated or "criteria"  
 39  
 40

1 air pollutants, which at sufficient concentrations can adversely affect human health and damage  
2 property.

3  
4 Tighter CAFE standards for light-duty trucks will reduce gasoline consumption and the amount  
5 of petroleum refined, and both of these effects will in turn reduce emissions of greenhouse gases.  
6 While reduced gasoline refining will also lower emissions of criteria pollutants, the increase in  
7 vehicle use that results from improving their fuel economy via the rebound effect will raise  
8 emission of these pollutants. Thus on balance, CAFE standards can reduce or increase emissions  
9 of criteria pollutants, depending on vehicles' emission rates per mile driven and on the size of the  
10 rebound effect.

11  
12 Fuel savings from stricter light truck CAFE standards will result in lower emissions of carbon  
13 dioxide, the main greenhouse gas emitted as a result of refining, distribution, and use of  
14 transportation fuels.<sup>37</sup> Lower fuel consumption reduces carbon dioxide emissions directly,  
15 because the primary source of these emissions in transportation is fuel use in internal combustion  
16 engines. We calculate reductions in carbon dioxide emissions from vehicle operation by  
17 multiplying the volume of fuel consumed by the amount of carbon converted to carbon dioxide  
18 during the combustion process per unit volume of fuel.<sup>38</sup>

19  
20 Direct or "tailpipe" carbon emissions (in the form of carbon dioxide) generated during year  $t$   
21 from fuel consumption by vehicles of model  $k$  produced during model year  $MY$  are calculated  
22 from:

$$23 \quad C_{k,MY,t}^{ip} = g_{k,MY,t} c_f \quad (1.27)$$

24  
25 where  $c_f$  indicates the carbon content (by weight) per gallon of fuel. As with fuel use, this  
26 calculation is performed separately for carbon emissions resulting from gasoline and diesel fuel  
27 combustion. The carbon content of gasoline is assumed to be a weighted average of those for  
28 different types of gasoline in use (see Appendix C for fuel-specific carbon content and the  
29 assumed mix of gasoline types).

30  
31 As with fuel consumption, the effect of a proposed CAFE standard on carbon emissions from  
32 vehicle operation is measured by the difference in emissions with the proposed standard in effect  
33 and those with a baseline or other alternative standard. Denoting these  $CAFE_1$  and  $CAFE_0$  as  
34 previously, the change in carbon emissions from fuel consumed by vehicles of model  $k$  and  
35 model year  $MY$  during year  $t$  is

$$36 \quad C_{k,MY,t,CAFE1}^{ip} = (g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}) c_f \quad (1.28)$$

37  
38  

---

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

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

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

6  
 7 At the same time, changing the stringency of CAFE standards will affect carbon emissions  
 8 generated by fuel combustion and other energy use that occurs during crude petroleum  
 9 extraction, transportation and storage, and refining to produce each type of fuel, as well as during  
 10 the storage and distribution of refined fuel (often referred to as "upstream" emissions). Carbon  
 11 emissions from each of these activities are calculated using estimates of emission rates per unit  
 12 of fuel energy refined and distributed to retail fueling stations.

13  
 14 These estimates are converted to a per-gallon basis using the energy content of different types of  
 15 gasoline and of diesel fuel, and used to calculate total carbon emissions per gallon of fuel used.  
 16 For vehicles of model  $k$  and model year  $MY$ , total carbon emissions during year  $t$  from fuel  
 17 production, distribution, and use are calculated as:

$$18 \quad C_{k,MY,t}^{tot} = g_{k,MY,t} (c_f + r \cdot c_r + c_d) \quad (1.29)$$

19  
 20 where as above  $c_f$  is the carbon content of each fuel type,  $c_r$  includes carbon emissions per gallon  
 21 during crude petroleum extraction, transportation, and refining to produce that type of fuel,  $c_d$   
 22 represents carbon emissions per gallon during storage and distribution of refined fuel, and  $r$  is the  
 23 fraction of that fuel type refined domestically (rather than imported directly). The values of  
 24 these parameters are specified in Appendix C.

25  
 26  
 27 The effect of replacing an initial or baseline standard  $CAFE_0$  with an alternative standard  $CAFE_1$   
 28 on total carbon emissions from fuel production and use is:

$$29 \quad C_{k,MY,t,CAFE1}^{tot} - C_{k,MY,t,CAFE0}^{tot} = (g_{k,MY,t,CAFE1} - g_{k,MY,t,CAFE0}) (c_f + r \cdot c_r + c_d) \quad (1.30)$$

30  
 31  
 32 Again, this quantity can be summed over vehicle models and ages to estimate the effect of a  
 33 proposed standard on total carbon emissions during any future year, or over vehicle types and  
 34 years to estimate the standard's effect on lifetime total carbon emissions of vehicles affected by  
 35 it.

### 36 37 C.3. Air Pollutant Emissions

38  
 39 Stricter CAFE standards can result in higher or lower emissions of regulated or "criteria" air  
 40 pollutants, by-products of fuel combustion that are emitted in extremely small amounts by the  
 41 internal combustion engines used to power light-duty vehicles as well as in gasoline refining and  
 42 distribution. Criteria pollutants emitted in significant quantities by light-duty motor vehicles  
 43 include carbon monoxide, various hydrocarbon compounds, nitrogen oxides, sulfur dioxide, and  
 44 fine particulate matter.

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

7  
 8 Emissions of pollutant  $i$  resulting from the operation of vehicle model  $k$  and model year  $MY$ ,  
 9 during year  $t$  are calculated as:

$$10 \quad E_{i,k,MY,t}^{op} = (M_{k,MY,t} - \Delta M_{k,MY,t}) e_{i,k,MY,t} \quad (1.31)$$

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

17  
 18  
 19 Changes in the volume of fuel consumption from varying CAFE standards will also affect  
 20 emissions of criteria pollutants that occur during refining, distribution, and retailing of gasoline  
 21 and diesel fuel.<sup>39</sup> As with greenhouse gas emissions, these "upstream" emissions are estimated  
 22 by applying emission factors for each criteria pollutant per unit of fuel refined to the total volume  
 23 of each type of fuel consumed with any specified CAFE standard in effect.

24  
 25 Upstream emissions of pollutant  $i$  generated in producing and distributing each type of fuel  
 26 consumed by vehicles of model  $k$  and vintage  $MY$  during year  $t$  are:

$$28 \quad E_{i,k,MY,t}^{up} = g_{k,MY,t} (r \cdot e_{i,r} - e_{i,d}) \quad (1.32)$$

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

33  
 34  
 35 Total emissions of criteria pollutant  $i$  from the production, distribution, and use of fuel are the  
 36 sum of emissions during vehicle operation and from the production and distribution of fuel:

$$38 \quad E_{i,k,MY,t}^{tot} = E_{i,k,MY,t}^{op} + E_{i,k,MY,t}^{up} \quad (1.33)$$

39  


---

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

1 In turn, the effect on criteria pollutant emissions of substituting standard CAFE<sub>1</sub> for an  
2 alternative standard CAFE<sub>0</sub> is

$$3 \quad E_{i,k,MY,J,CAFE1}^{tot} = (\Delta M_{k,MY,J,CAFE1} - \Delta M_{k,MY,J,CAFE0}) e_{i,k,MY,J} \quad (1.34)$$

$$4 \quad + (g_{k,MY,J,CAFE1} - g_{k,MY,J,CAFE0}) (r \cdot e_{i,r} + e_{i,d})$$

5  
6 As usual, this quantity can be summed over model or calendar years to report annual or lifetime  
7 effects of proposed CAFE standards on emissions of criteria pollutants.

8  
9 Emissions of some criteria pollutants are likely to increase as a result of stricter CAFE standards,  
10 as increased emissions from added driving due to the rebound effect outweigh the reduction in  
11 emissions from gasoline refining and distribution. For other pollutants, however, emission rates  
12 during fuel production are large relative to those from vehicle operation, so the reverse is likely  
13 to be true. As a result, the pattern of net changes in criteria pollutant emissions varies  
14 significantly, both over future years and among individual pollutants during any year.

### 15 16 17 18 **C.6. Private and Social Costs and Benefits**

19  
20 Improving the fuel efficiency of new vehicles produces a wide range of benefits and costs, some  
21 of which affect buyers of those vehicles directly, while others are borne more broadly by society  
22 as a whole. Depending upon how manufacturers attempt to recoup the costs they incur for  
23 improving the fuel efficiency of selected models, buyers are likely to face higher prices for some  
24 – and perhaps even most – new vehicle models. Purchasers of models whose fuel economy is  
25 improved benefit from the resulting savings in the value of fuel their vehicles consume, from any  
26 increase in the range they can travel before needing to refuel, and from the added driving they do  
27 as a result of the rebound effect. Depending on the technology manufacturers use to improve  
28 fuel economy and its consequences for vehicle power and weight, these benefits may be partly  
29 offset by a slight decline in the performance of some new models.

30  
31 At the same time, the reduction in fuel production and use resulting from improved fuel economy  
32 produces certain additional benefits and costs to society as a whole. Potential social benefits  
33 from reduced fuel use include any value society attaches to fuel savings over and above its  
34 private value to new vehicle buyers, lower emissions of air pollutants and greenhouse gases  
35 generated by from fuel production, distribution, and consumption, and reduced economic costs  
36 associated with U.S. imports of crude petroleum and refined fuel. By causing some additional  
37 driving through the rebound effect, improving fuel economy can also increase a variety of social  
38 costs, including the economic value of health effects and property damages caused by increased  
39 air pollution, the value of time delays to motorists from added traffic congestion, added costs of  
40 injuries and property damage resulting from more frequent traffic accidents, and economic costs  
41 from higher levels of traffic noise.

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

### 7 8 *Benefits and Costs to New Vehicle Buyers*

#### 9 10 *Increases in New Vehicle Prices*

11  
12 Depending upon how manufacturers attempt to recover the costs they incur in complying with  
13 CAFE regulations, purchase prices for some new models are likely to increase. Because we  
14 assume that manufacturers fully recover all costs they incur for installing fuel economy  
15 technologies to comply with CAFE in the form of higher prices for some models, the total  
16 increase in vehicle sales prices has already been accounted for in estimating technology costs to  
17 manufacturers. Nevertheless, the total value of these price increases represent a cost of CAFE  
18 regulation from the viewpoint of new buyers of models whose prices rise.

19  
20 In addition to increases in the prices paid by buyers who elect to purchase these models even at  
21 their higher prices, higher prices result in losses in welfare or consumer surplus to buyers who  
22 decide to purchase different models instead. These losses are extremely complex to estimate if  
23 prices change for a large number of models, and in any case are likely to be small even in total.  
24 Thus we do not attempt to estimate their value.

#### 25 26 *The Value of Fuel Savings*

27  
28 We estimate the economic value of fuel savings to buyers of new vehicle models whose fuel  
29 economy is improved as part of their manufacturers' efforts to comply with stricter CAFE  
30 standards by applying the Energy Information Administration's *Annual Energy Outlook* forecast  
31 of future fuel prices to each year's estimated fuel savings for those models. The annual fuel  
32 savings for a model during each year of its lifetime in the vehicle fleet is multiplied by the  
33 number of those initially sold that are expected to remain in use during that year to determine the  
34 total annual value of fuel savings to buyers of that model.

35  
36 The forecast retail price of fuel per gallon—including federal and average state fuel and other  
37 taxes—during that year is used to estimate the value of these fuel savings as viewed from the  
38 perspective of their buyers. Based on evidence from previous studies of consumer purchases of  
39 automobiles and durable appliances, we assume that new vehicle buyers value these savings over  
40 the approximate number of years they expect to own a new vehicle, and that buyers discount  
41 these expected savings to the year in which they purchase new vehicles.

#### 42 43 *Benefits from Additional Driving*

44  
45 The rebound effect results in additional benefits to new vehicle buyers in the form of consumer  
46 surplus from the increased driving it produces. These benefits arise from the value to drivers and



1 passengers of the social and economic opportunities made available to them by additional  
2 traveling. As evidenced by the fact that they elect to make more frequent or longer trips when  
3 improved fuel economy reduces the cost of driving, the benefits from this additional travel  
4 exceed the costs drivers and their passengers incur in making more frequent or longer trips. The  
5 amount by which these benefits from additional travel exceed its cost—which has been reduced  
6 by lower fuel consumption—represents the increase in consumer surplus associated with  
7 additional rebound effect driving.

8  
9 Our analysis estimates the value of these benefits using the conventional approximation, which is  
10 one half of the product of the decline in fuel cost per mile driven in vehicle models with  
11 increased fuel economy and the resulting increase in the annual number of miles they are driven.  
12 This value is calculated for each year that a model whose fuel economy is improved remains in  
13 the fleet, multiplied by the number of vehicles of that model expected to remain in use during  
14 each year of its lifetime, and discounted to its present value as of the year it was purchased. This  
15 benefit is likely to be small by comparison to most other economic impacts of raising CAFE  
16 standards.

17  
18 *The Value of Extended Refueling Range*

19  
20 Manufacturers' efforts to improve the fuel economy of selected new vehicle models will also  
21 increase their driving range between refueling. By reducing the frequency with which drivers  
22 typically refuel their vehicles, and by extending the upper limit of the range they can travel  
23 before requiring refueling, improving fuel economy thus provides some additional benefits to  
24 their owners.<sup>42</sup> No direct estimates of the value of extended vehicle range are readily available,  
25 so our analysis calculates the reduction in the annual number of required refueling cycles that  
26 results from improved fuel economy.

27  
28 The change in required refueling frequency for vehicle models with improved fuel economy  
29 reflects the increased driving associated with the rebound effect, as well as the increased driving  
30 range stemming from higher fuel economy.

31  

---

<sup>42</sup> 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.

1 *Changes in Performance and Utility*

2  
3 In its recent report on CAFE, the NAS assumed that, when applying efficiency-related  
4 technologies in response to CAFE standards, manufacturers would hold vehicle performance and  
5 utility constant. We make the same assumption.

6  
7 *Social Benefits and Costs from Increased Fuel Economy*

8  
9 *The "Social Value" of Fuel Savings*

10  
11 The economic value to society of the annual fuel savings resulting from stricter CAFE standards  
12 is also assessed by applying estimated future fuel prices to each year's estimated fuel savings.  
13 Unlike the value of fuel savings to vehicle buyers themselves, however, the *pre-tax* price per  
14 gallon is used in assessing the value of fuel savings *to the economy as a whole*. This is because  
15 reductions in revenues generated by state and federal taxes on fuel will be exactly offset by  
16 reduced spending on the government programs -- mainly construction and maintenance of streets  
17 and highways -- they are used to finance, and thus do not reflect a net savings in resources to the  
18 economy.

19  
20 When estimating the nationwide aggregate economic benefits and costs from CAFE regulation,  
21 we include this "social" value of fuel savings rather than their private value to vehicle buyers. In  
22 computing the social value of fuel savings, we include their annual value over the entire expected  
23 lifetimes of vehicle models whose fuel economy is improved, reflecting the presumably longer-  
24 term horizon of society as a whole compared to that of vehicle buyers, who may be concerned  
25 with fuel savings only over the time they expect to own newly-purchased vehicles.

26  
27 *Economic Benefits from Reduced Petroleum Imports*

28  
29 Importing petroleum into the United States is widely believed to impose significant costs on  
30 households and businesses that are not reflected in the market price for imported oil, and thus are  
31 not borne by consumers of refined petroleum products. These costs include three components:  
32 (1) higher costs for oil imports resulting from the combined effect of U.S. import demand and  
33 OPEC market power on the world oil price; (2) the risk of reductions in U.S. economic output  
34 and disruption of the domestic economy caused by sudden reductions in the supply of imported  
35 oil; and (3) costs for maintaining a U.S. military presence to secure imported oil supplies from  
36 unstable regions, and for maintaining the Strategic Petroleum Reserve (SPR) to cushion against  
37 price increases. By reducing domestic demand for gasoline, tighter CAFE standards may reduce  
38 petroleum imports, thus lowering some or all of these external or social costs to the U.S.  
39 economy from importing oil. If so, this represents an additional category of economic benefits  
40 from tighter fuel economy standards.

41  
42 Demand costs for imported oil (often termed "monopsony" costs) arise because the world oil  
43 price appears to be partly determined through the exercise of market power by the OPEC cartel,  
44 and because the U.S. is a sufficiently large purchaser of foreign oil supplies that its purchases can  
45 affect the world price. The combination of OPEC market power and U.S. "monopsony" power  
46 means that increasing domestic petroleum demand that is met through higher oil imports can

1 cause the world price of oil to rise, and conversely that declining U.S. imports can reduce the  
2 world price of oil. Thus one consequence of increasing U.S. oil imports is an increase in the  
3 price paid for all oil consumed by the U.S., which is borne not only by purchasers of the  
4 additional imports, but also by all purchasers of imported and domestically-produced  
5 petroleum.<sup>43</sup>

6  
7 The key determinants of the magnitude of this demand cost are the degree of monopoly power  
8 over foreign oil supplies exercised by the OPEC cartel, and the role of U.S. imports in  
9 determining world oil demand. If OPEC exercises some monopoly power over international oil  
10 supplies and U.S. import demand can affect the world price, changes in the level of domestic  
11 petroleum imports can influence world prices, thus creating the demand component of the  
12 economic cost of importing additional oil into the U.S. Under these same conditions, reductions  
13 in U.S. demand for imported petroleum would *reduce* the world oil price, thus creating  
14 additional benefits for all domestic oil consumers beyond the savings they experience simply  
15 from purchasing less oil.

16  
17 The degree of current OPEC monopoly power is subject to considerable debate, but appears to  
18 have declined somewhat since the 1970s. Nevertheless, the consensus appears to be that OPEC  
19 remains able to exercise some degree of control over the response of world oil supplies to  
20 variation in world oil prices, so that the world oil market does not behave competitively. The  
21 extent of U.S. monopsony power is determined by a complex set of factors including the relative  
22 importance of U.S. imports in the world oil market, and the sensitivity of petroleum supply and  
23 demand to its world price among other participants in the international oil market. Most recent  
24 evidence suggests that variation in U.S. demand for imported petroleum continues to exert some  
25 influence on world oil prices, although this influence appears to be limited.

26  
27 The second component of the external economic costs of importing oil arises partly because the  
28 increase in oil prices triggered by a disruption in the supply of imported oil reduces the level of  
29 output that the U.S. economy can produce using its available resources. The resulting reduction  
30 in potential economic output depends on the extent and duration of any disruption in the supply  
31 of imported oil to the U.S., since these determine the resulting increase in prices for petroleum  
32 products, as well as on whether and how rapidly these prices return to their pre-disruption levels.  
33 Even if the price for imported oil returns to its original level, however, the nation's economic  
34 output will be at least temporarily reduced compared to the level that would have been possible  
35 without the disruption in oil supplies and consequent increase in energy prices.

36  
37 Because supply disruptions and resulting price increases occur suddenly rather than gradually,  
38 they also impose additional costs on businesses and households for adjusting their use of

---

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

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

8  
9 Since future disruptions in foreign oil supplies are an uncertain prospect, each of these two  
10 components of the disruption cost must be weighted or adjusted for the probability that the  
11 supply of imported oil to the U.S. will actually be disrupted. Thus the "expected value" of these  
12 costs -- the product of the probability that an oil import disruption will occur and the sum of costs  
13 from reduced economic output and the economy's abrupt adjustment to sharply higher petroleum  
14 prices -- is the usual measure of their magnitude. Further, only the *change* in their expected  
15 value that results from lowering the normal (pre-disruption) level of oil imports through a policy  
16 such as tightening CAFE standards is relevant when assessing its effect on the "true" cost of  
17 importing oil into the U.S.

18  
19 While the vulnerability of the U.S. economy to oil price shocks is widely thought to depend on  
20 *total* petroleum consumption rather than on the level of oil imports, variation in imports is still  
21 likely to have some effect on the potential price increase resulting from any disruption of import  
22 supply. In addition, changing the quantity of petroleum imported into the U.S may also affect  
23 the probability that such a disruption will occur. If the resulting price increase or the probability  
24 that U.S. oil imports will be disrupted is affected by their pre-disruption level, the expected value  
25 of the costs stemming from supply disruptions will also vary in response to the level of oil  
26 imports.

27  
28 An increasing number of market mechanisms -- including oil futures markets, energy  
29 conservation measures, and fuel switching possibilities -- are available within the U.S. economy  
30 for businesses and households to anticipate and "insure" themselves against the effects of  
31 petroleum price increases. While their availability has undoubtedly reduced the potential costs  
32 that could be imposed by disruptions in the supply of imported oil, the full expected value of  
33 these potential costs still may not be reflected in the market price of imported oil. Thus changes  
34 in oil import levels probably continue to affect the expected cost to the U.S. economy from  
35 potential oil supply disruptions, although the value of this component of oil import costs is likely  
36 to be significantly smaller than those estimated by studies conducted in the wake of the oil  
37 supply disruptions that occurred during the 1970s.

38  
39 The third component of the external economic costs of importing oil into the U.S. is usually  
40 identified as the costs to the U.S. taxpayers for maintaining a military presence to secure the  
41 supply of oil imports from potentially unstable regions of the world and protect the nation  
42 against their interruption. Some analysts also include the costs to federal taxpayers for  
43 maintaining the U.S. Strategic Petroleum Reserve, which is intended to cushion the U.S.  
44 economy against the consequences of disruption in the supply of imported oil, as additional costs  
45 of protecting the U.S. economy from such oil supply disruptions. Thus many analyses include  
46 part or all of the annual cost for U.S. military operations in the Persian Gulf (and occasionally

1 other regions of the world), together with the full costs of stocking and maintaining the SPR, as  
2 additional economic costs associated with importing oil into the U.S.

3  
4 However, there is little evidence that the magnitude of either of these costs is associated with  
5 *changes* in the actual level of oil imports into the U.S. that would result from policies such as  
6 tightening CAFE standards. In addition, military activities even in world regions that represent  
7 vital sources of oil imports undoubtedly serve a range of security and foreign policy objectives  
8 that is considerably broader than simply protecting oil supplies. As a consequence, the scope  
9 and duration of any specific U.S. military activities that were undertaken for the purpose of  
10 protecting imported oil supplies seem unlikely to be tailored to the actual volume of petroleum  
11 imports from the regions where they take place. Thus annual expenses to support U.S. military  
12 activities do not seem likely to vary closely in response to changes in the level of oil imports  
13 prompted by conservation efforts or other policies. More specifically, reductions in gasoline use  
14 resulting from stricter CAFE standards seem unlikely to result in savings in the military budget  
15 that could be included as additional benefits.

16  
17 Similarly, while the optimal size of the SPR from the standpoint of its potential influence on  
18 domestic oil prices during a supply disruption may be related to the level of U.S. oil consumption  
19 and imports, its actual size has not appeared to vary in response to recent changes in the volume  
20 of oil imports. Thus while the budgetary costs for maintaining the Reserve are similar to other  
21 external costs in that they are not likely to be reflected in the market price for imported oil, these  
22 costs have not varied in response to changes in oil import levels (although in theory they might  
23 ideally do so). As a result, this analysis does not include any cost savings from maintaining a  
24 smaller SPR among the external benefits of reducing gasoline consumption and petroleum  
25 imports by means of a tighter CAFE standard for light-duty trucks.

26  
27 In this analysis, the reduction in petroleum imports resulting from higher light truck CAFE  
28 standards is estimated by assuming that the resulting savings in gasoline use during each future  
29 year is translated directly into a corresponding reduction in the annual volume of U.S. oil imports  
30 during that same year. The value to the U.S. economy of reducing petroleum imports -- in the  
31 form of lower crude oil prices and reduced risks of oil supply disruptions -- is estimated by  
32 applying the sum of the previously-reported estimates of these benefits to the estimated annual  
33 reduction in oil imports.

#### 34 35 *Valuing Changes in Environmental Impacts*

36  
37 Environmental impacts from petroleum use occur primarily as a result of petroleum refining and  
38 the distribution and combustion of petroleum products such as gasoline. These impacts include  
39 emissions of greenhouse gases, which are widely believed to increase the potential for global  
40 climate change, and of regulated or "criteria" air pollutants, which can adversely affect human  
41 health and damage property in sufficient concentrations. Emissions of greenhouse gases and  
42 criteria pollutants occur during petroleum refining, as well as during the subsequent distribution  
43 and consumption of petroleum products such as gasoline. Stricter CAFE standards will reduce  
44 gasoline consumption and the amount of petroleum refined, and both of these effects will in turn  
45 reduce emissions of greenhouse gases. While reduced gasoline refining and distribution will also  
46 lower emissions of criteria pollutants, the increased driving that results from improving the fuel

1 economy of new vehicles will raise emissions of these pollutants. On balance, CAFE standards  
2 can thus reduce or increase emissions of criteria pollutants.

3  
4 We value the net change in emissions of each criteria pollutant to which gasoline refining and  
5 motor vehicle operation contribute significantly – carbon monoxide, volatile organic compounds,  
6 nitrogen oxides, sulfur dioxide, and fine particulates – using estimates of the value per ton of  
7 emissions of each pollutant that is eliminated.

### 8 9 *Social Costs of Added Driving*

10  
11 In addition to the slight increase in emissions of criteria pollutants, the added driving associated  
12 with the fuel economy rebound effect may contribute to increased traffic congestion, motor  
13 vehicle accidents, and highway noise. Additional vehicle use can contribute to traffic congestion  
14 and delays partly by increasing recurring congestion on heavily-traveled facilities during peak  
15 travel periods, depending on how the additional travel is distributed over the day and on where it  
16 occurs. Added vehicle use can also increase the frequency of incidents such as collisions and  
17 disabled vehicles that cause prolonged delays, although the extent to which it actually does do  
18 will again depend partly on when and where the added travel occurs. In either case, any added  
19 delays caused by additional vehicle use imposes higher costs on drivers and other vehicle  
20 occupants in the form of increased travel time and operating expenses, and these should be  
21 considered as an external cost associated with the increase in driving from the rebound effect.

22  
23 At the same time, the added light truck use due to the rebound effect may also increase the  
24 economic costs of injuries and property damage from traffic accidents. Drivers presumably take  
25 account of the potential costs they (and the other occupants of their vehicles) face from the  
26 possibility of being involved in an accident when they decide to make additional trips. However,  
27 they may not consider fully the potential costs they impose on occupants of other vehicles and on  
28 pedestrians, so any increase in these “external” accident costs that results from added rebound-  
29 effect driving must be estimated separately. Like increased delay costs, any increase in these  
30 external accident costs caused by added driving is likely to depend on the traffic conditions  
31 under which it takes place, since accidents are more frequent in heavier traffic, but their severity  
32 may be reduced by the slower speeds at which heavier traffic typically moves. Thus estimates of  
33 the increase in external accident costs from the rebound effect also need to account for when and  
34 where the added driving occurs.

35  
36 Finally, added light truck use from the rebound effect may also increase traffic noise. Noise  
37 generated by vehicles causes inconvenience, irritation, and potentially even discomfort to  
38 occupants of other vehicles, to pedestrians and other bystanders, and to residents or occupants of  
39 surrounding property. Because none of these effects are likely to be taken into account by the  
40 drivers whose vehicles contribute to traffic noise, it represents an additional externality  
41 associated with motor vehicle use. Although there is considerable uncertainty in estimating its  
42 value, the added inconvenience and irritation caused by increased traffic noise imposes economic  
43 costs on those it affects. Thus to the extent that added driving from the fuel economy rebound  
44 effect causes an increase in traffic noise, the resulting increase in these costs must be included  
45 together with other increased external costs from the rebound effect.

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

## Appendix A. Installation

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

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

The software uses the Microsoft® .NET Framework. If the Framework is not already present, it must be installed. Instructions are available on the Internet at [http://msdn.microsoft.com/netframework/downloads/framework1\\_1/](http://msdn.microsoft.com/netframework/downloads/framework1_1/).<sup>45</sup>

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

Based on the characteristics of machines used in the development of this software, Table A-1 provides a summary of system recommendations.

**Table A-1. System Recommendations**

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

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

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



1 **Appendix B. Operation**

2  
3 **Step 1: Install the software (see Appendix A) and put all the input files in a folder you can**  
4 **find.** The files are:

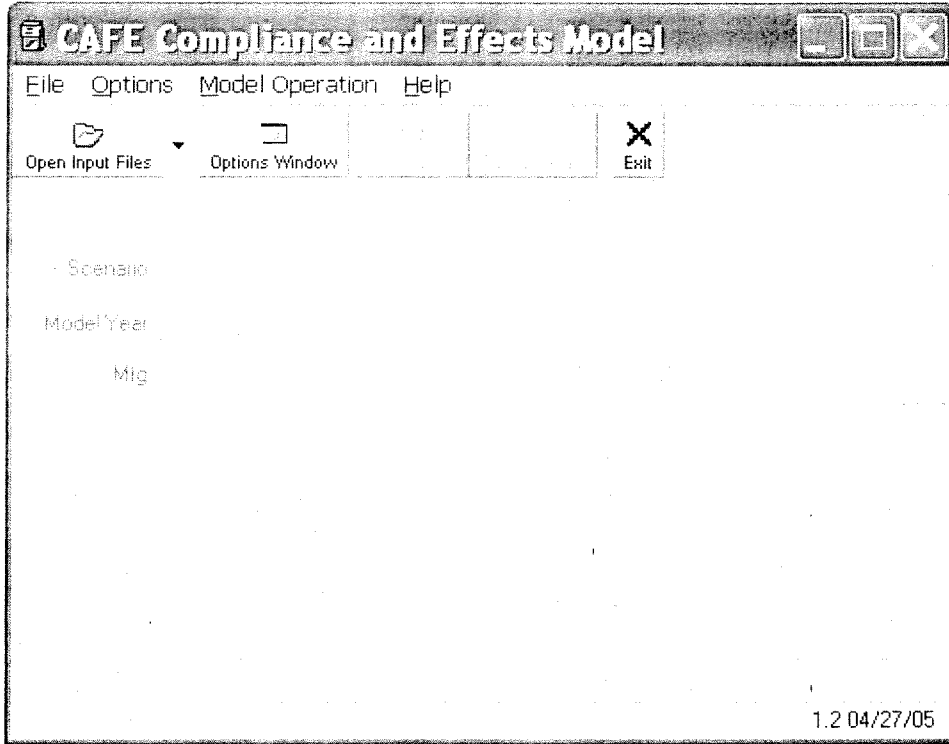
- 5  
6 • *demo\_parameters.xls*: inputs used to calculate the energy, emissions of changes in  
7 vehicle characteristics and sales volumes, as well as some assumptions used when  
8 simulating compliance  
9  
10 • *demo\_market\_data.xls*: vehicle model, engine, and transmission characteristics and  
11 vehicle model sales volumes  
12  
13 • *demo\_scenarios.xls*: inputs used to define different CAFE scenarios  
14  
15 • *demo\_technologies.xls*: technology cost, efficiency, and availability assumptions  
16

17 To protect confidential business information and otherwise protected information, the file  
18 defining the initial state of the fleet—*demo\_market\_data.xls*—contains fictitious data.

19 Therefore, when used with this file, the system will produce fictitious results.

20 Though useful for diagnostic purposes, such results should be treated as otherwise meaningless,  
21 and should not be cited or released.  
22

1 Step 2: After closing other applications (in particular, Excel), run the program to open the  
2 main control window.<sup>46</sup>  
3  
4

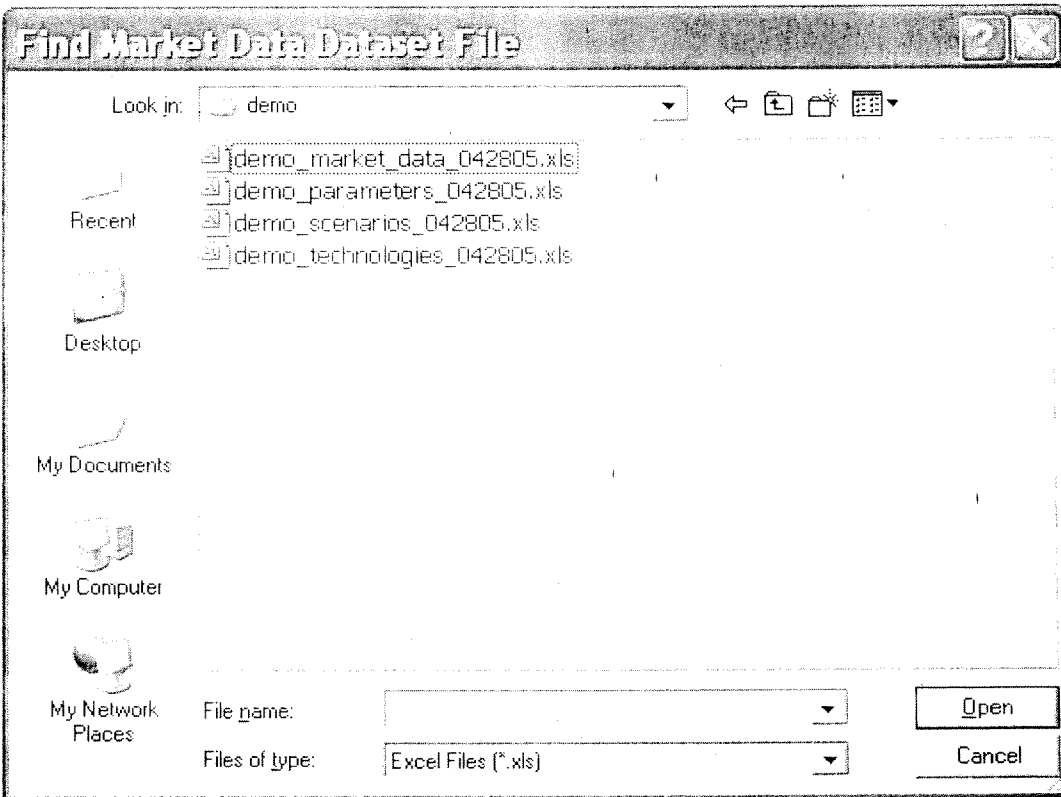


5  
6

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

1 Step 3: Use the “Open...Files” control buttons to specify the input file locations.

- 2
- 3 • Select “Open Market Data File” from the File menu and locate the market data file when
- 4 prompted.
- 5



- 6
- 7
- 8 • Click the “Open Other Files” and locate technologies, parameters, and benefits model
- 9 parameters files when prompted. (NOTE: To be able to select the benefits model
- 10 parameters file, first go to the “Other” tab located on the “Options” window and
- 11 check “Run the Effects Model at the end of each scenario”. See Step 4.)
- 12

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

2

3

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

4

The screenshot shows a dialog box titled "Options" with a tabbed interface. The "Technology Settings" tab is selected. It contains three sections: "Technology Paths" with radio buttons for Path 1, Path 2 (selected), and Path 3; "Technology Fuel Consumption Estimates" with radio buttons for Low, Average (selected), and High estimates; and "Technology Cost Estimates" with radio buttons for Low, Average (selected), and High cost estimates. At the bottom, there are buttons for "Model Years", "OK", and "Cancel".

5

- 1  
2  
3
- Click the “Operating Modes” tab and change settings as desired.<sup>47,48,49</sup>

4

**Options**

Technology Settings | **Operating Modes** | Encryption Settings | Output Settings | Other

Operating Modes

Select All Modes      Create Engine If:      All

No Fines       Cars Involved     Multiple RC     Tech Enable Miss Match

Low Cost Technology First      Create Transmission If:      All

Auto-invoke Efficiency Model       Cars Involved     Multiple RC     Tech Enable Miss Match

Back Fill Technology      Skip Engine/Transmission If:      All

Stage Analysis       Cars Involved     Multiple RC     Tech Enable Miss Match

Monte Carlo Analysis       Reserve Technologies If In Compliance

Iterations:

<sup>47</sup> add text to more fully explain operating modes

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

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

- Click the “Output Settings” tab. Specify default output path (recommend same as location of input files).
- Check “Hide Unused RCs” to omit cells in output files for unused regulatory classes.
- Check boxes for desired reports.

**Options**

Technology Settings | Operating Modes | Encryption Settings | **Output Settings** | Other

General

Default Output Path  
 C:\cafe\runs\Nat\_standard\_comparisons\_043005\oldmc  
 Hide Unused RCs

Report Settings

Generate All Reports  
 Generate Industry Report  
 Generate Manufacturers Report  
 Generate Vehicles Report  
 Generate Effects Report  
 Generate Environmental Assessment Report

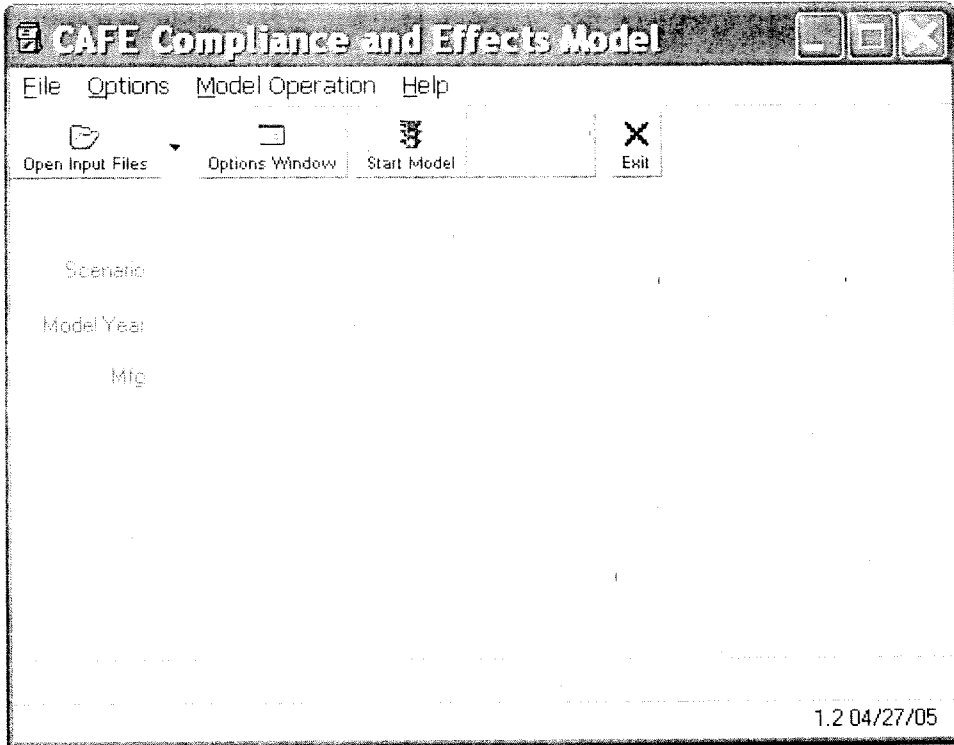
Template Settings

Use Templates for Output  
 C:\cafe\data\Template.xls

Model Years | Apply | OK | Cancel

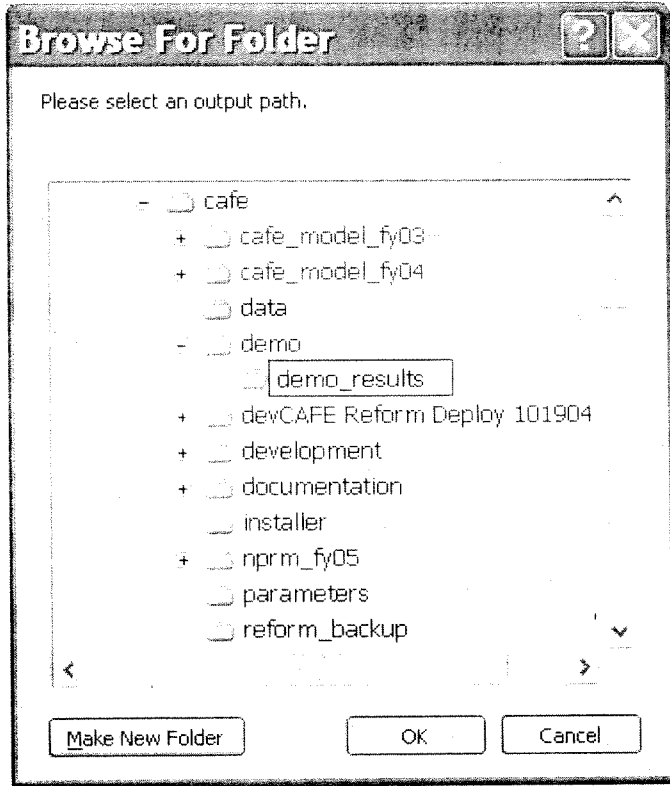
- If template files were included in the installed input files, click the “Templates” tab to specify their use and location. These files speed the production of output files.

- 1 Step 5. Return to the main control window and click "Start Model", which should be "lit".
- 2



- 3
- 4

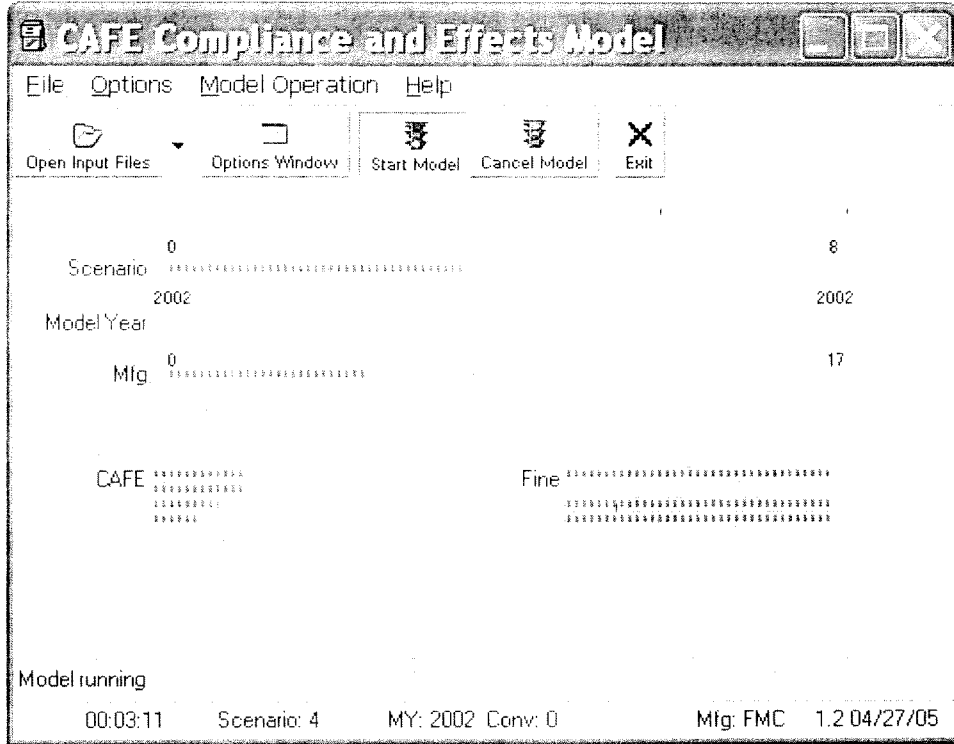
- 1 Step 6. Specify a location into which to place output files. Create a new folder if desired.
- 2



3

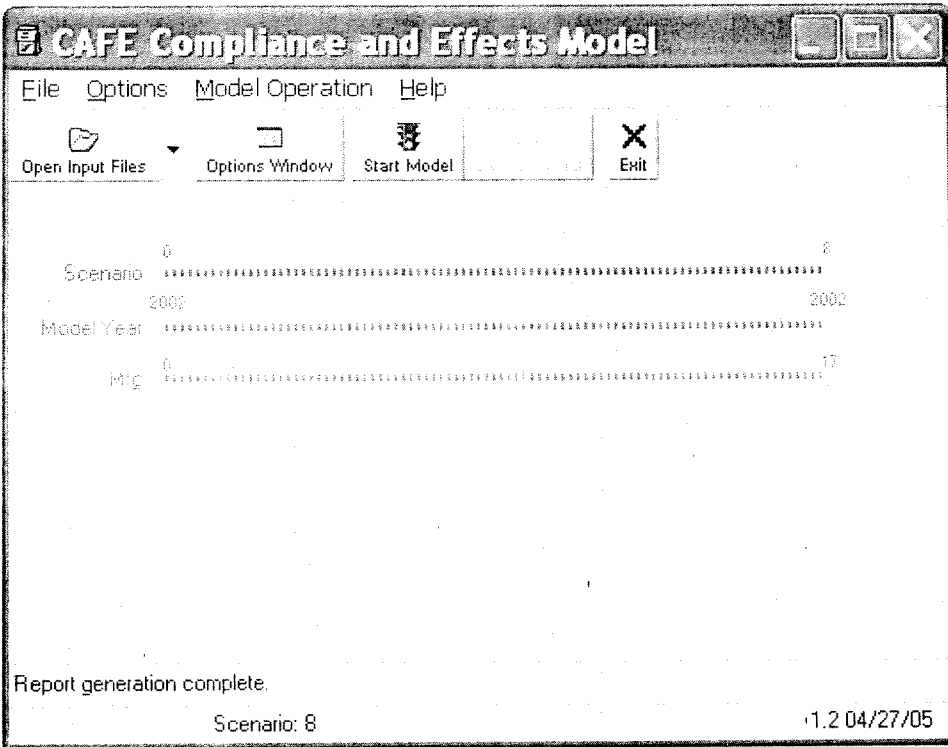


- 1 • While the compliance model is running, various status bars and other indicators are used  
2 to show progress. When running multiple CAFE scenarios, overall progress is most  
3 clearly indicated by the "Scenario" (topmost) status bar.  
4



5

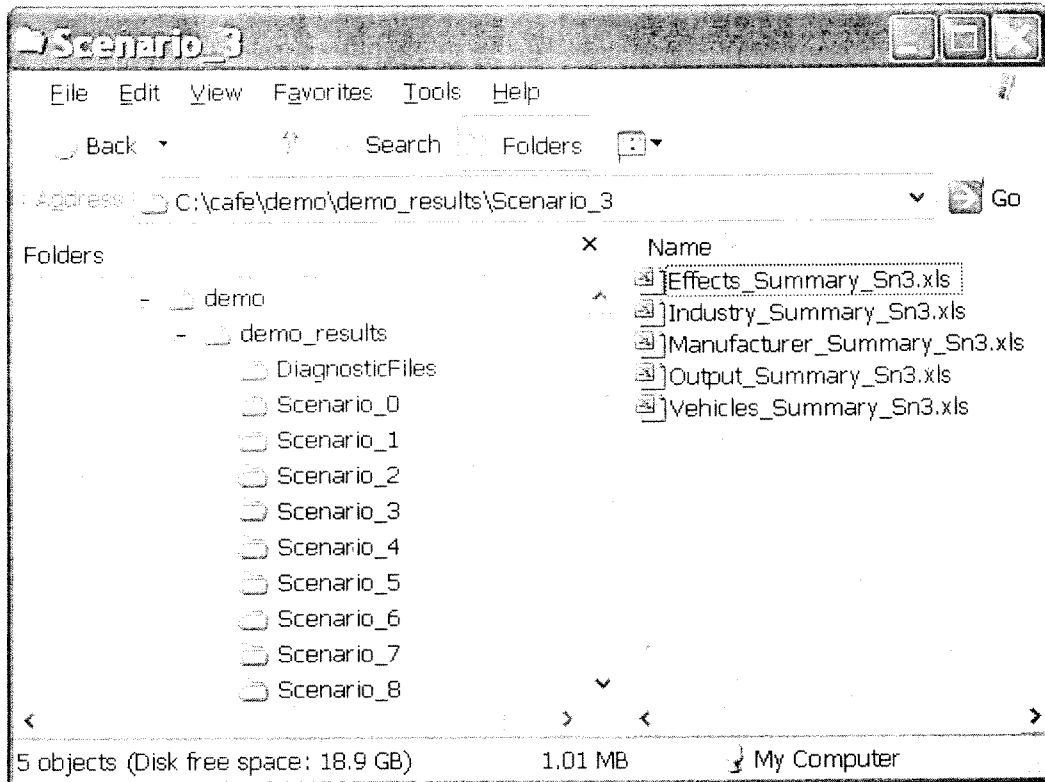
- 1 • The modeling and reporting have concluded when “Modeling complete” appears toward  
2 the bottom of the main control window.  
3



- 4
- 5
- 6
- 7 **Step 7. Click the “Exit” button on the main control window to close the program.**
- 8

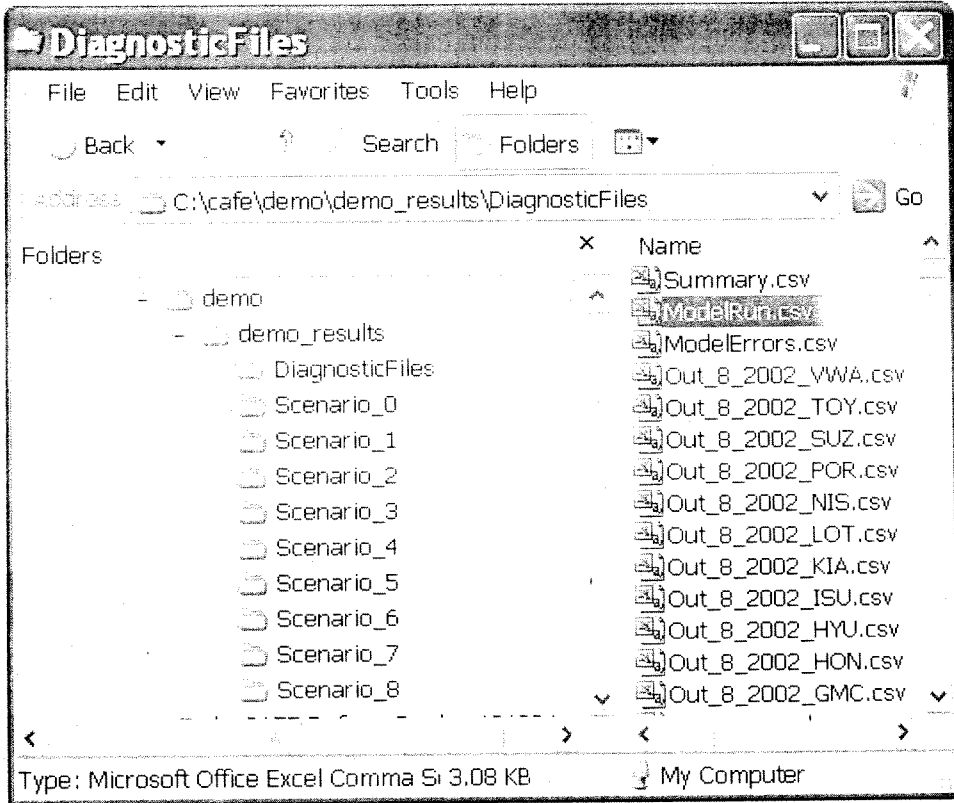
1 **Step 9. View results by opening appropriate output files.** The files are organized using one  
 2 folder to hold results for included scenarios, which are numbered in order of appearance, starting  
 3 at 0. The first scenario (0) is identified as the baseline scenario to which all others are compared.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

- 5
- 6 • *Effects\_Summary\_Sn\*.xls*: Summary of energy, emissions effects.
- 7
- 8 • *Industry\_Summary\_Sn\*.xls*: Industry-level summary of compliance model results.
- 9
- 10 • *Manufacturer\_Summary\_Sn\*.xls*: Manufacturer-level summary of compliance model
- 11 results.
- 12
- 13 • *Vehicles\_Summary\_Sn\*.xls*: Vehicle-level summary of compliance model results.
- 14



15  
 16  
 17 To protect confidential business information and otherwise protected information, the file  
 18 defining the initial state of the fleet—*demo\_market\_data.xls*—contains fictitious data.  
 19 Therefore, when used with this file, the system will produce fictitious results.  
 20 Though useful for diagnostic purposes, such results should be treated as otherwise meaningless,  
 21 and should not be cited or released.

1 To review input files, model settings, and scenario descriptions, open *ModelRun.csv*, which is in  
2 the *DiagnosticFiles* folder.  
3



4  
5

1 **Appendix C. Inputs**

2  
3 *Overview*

4  
5 In addition to various operational settings that are, as discussed in Appendix B, specified by the  
6 user at the time the system is initiated, the system utilizes the three input files (all in Microsoft®  
7 Excel format) shown in Table C-.<sup>50</sup> As discussed in Appendix B, the user specifies the location  
8 of these files in the course of setting up a model run.

9  
10 **Table C-1. Input File Contents**

11

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

12

<sup>50</sup> Until recently, the vehicle models, engines, and transmissions worksheet were contained in separate input files.

<sup>51</sup> add reference

1 *Vehicle Models Worksheet*

2  
 3 The vehicle models worksheet contains information regarding each vehicle model offered for  
 4 sale during the study period. Each vehicle model is represented as a single row of input data.  
 5 Table C-2 lists the different columns of information specified in the vehicle models file. To  
 6 make the information readable, Table C-2 is presented vertically and divided into sections.  
 7

8 In the “General” category, the number, manufacturer, fuel economy, engine code, and  
 9 transmission code must be specified for each vehicle model. The engine and transmission codes  
 10 must refer to a valid engine and transmission, respectively, for the relevant manufacturer in the  
 11 engine and transmission input files. Known or projected sales are specified in the “Sales”  
 12 section for each model year in which the model is offered. Changes to a model—in particular  
 13 any (e.g., a different engine or transmission) that would affect fuel economy—are specified by  
 14 creating a new row (effectively a new vehicle model) with the older model’s number in the  
 15 “predecessor” field (discussed below).  
 16  
 17  
 18

Table C-2. Vehicle Models Worksheet

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

19

1 Within the "Vehicle" category, it is important that each vehicle model's style, class, drive,  
 2 overall length, overall width, curb weight, maximum seating capacity, and fuel capacity be  
 3 specified. For any hybrid vehicle models, it is necessary to specify at least the type of  
 4 hybridization.  
 5  
 6  
 7

Table C-2. Vehicle Models (continued)

Category	Model Characteristic	Units	Definition/Notes
Vehicle	Style	text	
	Class	text	vehicle class
	Structure	text	
	Drive	text	
	Final Drive Ratio	number	minimum gear ratio in differential (i.e., rear axle ratio for RWD vehicle)
	N/V	rpm/mph	average ratio of engine speed (rpm) divided by vehicle speed (mph) in top gear
	Front Axle Lubricant Viscosity	text	viscosity of front axle lubricant
	Rear Axle Lubricant Viscosity	text	viscosity of rear axle lubricant
	Overall Length	inches	per SAE J1100, L105 (July 2002)
	Overall Width	inches	per SAE J1100, W116 (July 2002)
	Overall Height	inches	per SAE J1100, H100 (July 2002)
	Wheelbase	inches	per SAE J1100, L101 (July 2002)
	Track Width (front)	inches	per SAE J1100, W101-1 (July 2002)
	Track Width (rear)	inches	per SAE J1100, W101-2 (July 2002)
	Ground Clearance	inches	per 49CFR523
	Front Axle Clearance	inches	per 49CFR523
	Rear Axle Clearance	inches	per 49CFR523
	Angle of Approach	degrees	per 49CFR523
	Breakover Angle	degrees	per 49CFR523
	Angle of Departure	degrees	per 49CFR523
	Height of Center of Gravity	inches	per NCAP
	Curb Weight	pounds	
	Test Weight	pounds	
	PAU Setting	horsepower	power absorption unit setting
	GVWR	pounds	Gross Vehicle Weight Rating: weight of loaded vehicle, including passengers and cargo
	Towing Capacity (standard)	pounds	standard amount of weight that may be pulled given standard vehicle equipment
	Towing Capacity (max)	pounds	maximum amount of weight that may be pulled given optional vehicle packages
	Payload	pounds	weight of cargo and occupants that may be carried in the vehicle
	Seating (min)	integer	number of usable seat belts after folding and removal of seats (where accomplished without special tools)
	Seating (max)	integer	number of usable seat belts before folding and removal of seats (where accomplished without special tools)
	Seating in First Row	integer	number of usable seat belts in first row before folding and removal of seats
	Cargo Vol. Behind First Row	cubic feet	per SAE J1100, Table 28 (July 2002)
	Seating in Second Row	integer	number of usable seat belts in second row before folding and removal of seats
	Second Row Flat Capability	text	does folding or removal of second row seats leave a flat surface flush with rearmost cargo area?
	Cargo Vol. Behind Second Row	cubic feet	per SAE J1100, Table 28 (July 2002)
	Seating in Third Row	integer	number of usable seat belts in third row before folding and removal of seats
	Third Row Flat Capability	text	does folding or removal of third row seats leave a flat surface flush with rearmost cargo area?
	Cargo Vol. Behind Third Row	cubic feet	per SAE J1100, Table 28 (July 2002)
	Enclosed Volume	cubic feet	total interior volume of vehicle
	Passenger Volume (standard)	cubic feet	passenger volume after folding and removal of seats (where accomplished without special tools)
	Passenger Volume (max)	cubic feet	passenger volume before folding and removal of seats (where accomplished without special tools)
	Cargo Volume Index	cubic feet	per SAE J1100, Table 28 (July 2002)
	Open Box Area Length	inches	per SAE J1100, L506 (July 2002)
Open Box Area Width (min)	inches	per SAE J1100, W201 (July 2002)	
Open Box Area Width (max)	inches	per SAE J1100, W500 (July 2002)	
Open Box Area	square feet	product of (1) open box length and (2) average of min. and max. box width	
Open Box Height	inches	per SAE J1100, H503 (July 2002)	
Fuel Capacity	gallons	gallons of diesel fuel or gasoline, MJ (LHV) of other fuels (or chemical battery energy)	
Tire Rolling Resistance	number	Crr	
Frontal Area	square feet		
Aerodynamic Drag Coefficient	number	Cd	
Vehicle Notes	text (up to 255 characters)	explanatory notes	
Hybridization	Type	text	
	Voltage (or Pressure)	volts or psi	voltage of HEV battery or pressure of hydraulic hybrid accumulator
	Energy Storage Capacity	MJ	maximum energy (megajoules) stored in battery or accumulator
	Battery Type	text	
	Energy Transfer	text	transfer between brake and stored energy
	Braking Energy Recovery	percent	percentage of braking energy recovered and stored
	Share of Maximum Power	percent	percentage of maximum motive power provided by stored energy system
	Hybridization Notes	text (up to 255 characters)	explanatory notes

8

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

Table C-2. Vehicle Models (continued)

Category	Model Characteristic	Units	Definition/Notes
Planning & Assembly	Predecessor	integer	number of model upon which current model is based
	Last Freshening	model year	
	Next Freshening	model year	
	Last Redesign	model year	
	Next Redesign	model year	
	U.S./Canadian Content	percent	overall percentage, by value, that originated in U.S. or Canada
	Final Assembly City	text	city of the final assembly point
	Final Assembly State	text	state of the final assembly point
	Final Assembly Country	text	country of the final assembly point
	Employment Hours per Vehicle	hours	hours of U.S. manufacturing employment per vehicle
Planning & Assembly Note:	text (up to 255 characters)	explanatory notes	
MSRP	MY2002	dollars (2005)	average MSRP
	MY2005	dollars (2005)	projected average MSRP
	MY2004	dollars (2005)	projected average MSRP
	MY2005	dollars (2005)	projected average MSRP
	MY2006	dollars (2005)	projected average MSRP
	MY2007	dollars (2005)	projected average MSRP
	MY2008	dollars (2005)	projected average MSRP
	MY2009	dollars (2005)	projected average MSRP
	MY2010	dollars (2005)	projected average MSRP
	MY2011	dollars (2005)	projected average MSRP
	MY2012	dollars (2005)	projected average MSRP
	MSRP Notes	text (up to 255 characters)	explanatory notes

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

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



Table C-2. Vehicle Models (continued)

Category	Model Characteristic	Units	Definition/Notes
Emissions	EPA Class	text	Tier 2 Class
	EPA Certification Bin	integer	Tier 2 Bin
	LEV Class	text	
	Emissions Notes	text (up to 255 characters)	explanatory notes
LT Definition	LTDNF1	boolean	definition as nonpassenger automobile under alternative definition #1
	LTDNF2	boolean	definition as nonpassenger automobile under alternative definition #2
	LTDNF3	boolean	definition as nonpassenger automobile under alternative definition #3
	LTDNF4	boolean	definition as nonpassenger automobile under alternative definition #4
	LTDNF5	boolean	definition as nonpassenger automobile under alternative definition #5
HLT Definition	HLTDFN1	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #1
	HLTDFN2	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #2
	HLTDFN3	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #3
	HLTDFN4	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #4
	HLTDFN5	boolean	for vehicles over 8,500, coverage under alternative inclusion policy #5
Effects	Safety Class	text	classification per recent NHTSA report on safety
	MOBILE6 Class	text	classification per EPA MOBILE6 model
	% 2 DR Cars	percent	share of vehicle model with 2 or 3 doors
	Market Segment - VOLPE	text	not currently used
Technology Applicability Overrides	Market Segment - Auto News	integer	coded market share per 2002 Automotive News Market Classification
	ROLL	text	force system to "ALLOW" or "SKIP" low rolling resistance tires
	EPS	text	force system to "ALLOW" or "SKIP" electric power steering
	EAI	text	force system to "ALLOW" or "SKIP" engine accessory improvements
	AER	text	force system to "ALLOW" or "SKIP" aerodynamic drag reduction
	42V	text	force system to "ALLOW" or "SKIP" 42V electrical system
	ISG	text	force system to "ALLOW" or "SKIP" integrated starter/generator
	WGT	text	force system to "ALLOW" or "SKIP" weight reduction
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	
	[reserved]	text	

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1 *Engines Worksheet*

2  
3 Similar to the vehicle models input file, the engines input worksheet contains a list of all engines  
4 used in vehicle models offered for sale during the study period. For each manufacturer, the  
5 engine code is a unique number assigned to each such engine. This code is referenced in the  
6 engine code field of the vehicle models input file. For each engine, the engine code,  
7 manufacturer, fuel, cycle, number of cylinders, number of valves per cylinder, and horsepower  
8 must all be specified. As in the vehicle models worksheet, technology path overrides for any  
9 engine technology can be specified for any specific engine.

10  
11 **Table C-3. Engines Input Worksheet**

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

13  
14

1 *Transmissions Worksheet*

2  
3 Similar to the vehicle models and engines input worksheets, the transmissions input worksheet  
4 contains a list of all transmissions used in vehicle models offered for sale during the study  
5 period. For each manufacturer, the transmission code is a unique number assigned to each such  
6 transmission. This code is referenced in the transmission code field of the vehicle models input  
7 file. For each transmission, the transmission code, manufacturer, type, and control must all be  
8 specified. As in the vehicle models input worksheet, technology path overrides for any  
9 transmission technology can be specified for any specific transmission.

10  
11 **Table C-4. Transmissions Input File**

12

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

13  
14 Taken together, the vehicle models, engine, and transmissions input files provide "initial state"  
15 historical and/or forecast data for the light vehicle fleet.

16  
17  
18 For system development and testing, we have assembled these three input files by integrating  
19 information from several sources of data regarding the MY2002 fleet. For vehicles already  
20 subject to CAFE regulations (*i.e.*, all passenger and nonpassenger automobiles with GVW  
21 ratings under 8,500 pounds), we began with a NHTSA database containing fuel economy levels,  
22 sales volumes, and basic vehicle, engine, and transmission characteristics. To this database, we  
23 added significant information from different commercial sources, including Wards, Automotive  
24 News, and other sources.<sup>52</sup>

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

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

<sup>54</sup> add reference

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

## Technologies

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

Table C-5. Technologies Input File (Sample)

Small SUV Technology	Variables				Year Avail.	Path			Phase-in	kWeight	Abbr.	seq	TechType
	FC-Low	FC-High	Cost-Low	Cost-High		Path1	Path2	Path3					
Low Friction Lubricants	1.00%	1.00%	\$ 8.00	\$ 11.00	2008	TRUE	TRUE	TRUE	50%		LUB	1	EngMod
Improve Rolling Resistance	1.00%	1.50%	\$ 15.00	\$ 58.00	2008	TRUE	TRUE	TRUE	50%		ROLL	2	DLR
Low Drag Brakes	0.75%	1.25%	\$ 15.00	\$ 146.00	2008	TRUE	TRUE	TRUE	50%		LDB	3	DLR
Engine Friction Reduction	1.00%	5.00%	\$ 36.00	\$ 146.00	2008				33%		EFR	4	EngMod
Front Axle Disconnect (for 4WD)	1.50%	2.50%	\$ 100.00	\$ 110.00	2008				5%		FAD	5	DLR
Cylinder Deactivation	3.00%	6.00%	\$ 116.00	\$ 262.00	2008				25%		DISP	6	EngMod
Multi-Valve, Overhead Camshaft	2.00%	5.00%	\$ 109.00	\$ 146.00	2008	TRUE	TRUE	TRUE	33%		OHC	7	EngMod
Variable Valve Timing	2.00%	3.00%	\$ 36.00	\$ 146.00	2008	TRUE	TRUE	TRUE	33%		VVT	8	EngMod
Electric Power Steering	1.50%	2.50%	\$ 109.00	\$ 156.00	2008		TRUE	TRUE	33%		EPS	9	ALR
Engine Accessory Improvement	1.00%	2.00%	\$ 87.00	\$ 116.00	2008	TRUE	TRUE	TRUE	33%		EAI	10	ALR
5-Speed Automatic Transmission	2.00%	3.00%	\$ 73.00	\$ 160.00	2008	TRUE	TRUE		33%		5SP	11	TrMod
6-Speed Automatic Transmission	1.00%	2.00%	\$ 146.00	\$ 291.00	2008				25%		6SP	12	TrMod
Automatic Transmission w/ Aggressive Shift Logic	1.00%	3.00%	\$ -	\$ 73.00	2008				33%		ASL	13	TrMod
Continuously Variable Transmission (CVT)	4.00%	8.00%	\$ 146.00	\$ 364.00	2008		TRUE	TRUE	33%		CVT	14	TrMod
Automatic Shift Manual Transmission (AST/AMT)	3.00%	5.00%	\$ 73.00	\$ 291.00	2010				10%		AST	15	TrMod
Aero Drag Reduction	1.00%	2.00%	\$ -	\$ 146.00	2008		TRUE	TRUE	33%		AER	16	AERO
Variable Valve Lift & Timing	1.00%	2.00%	\$ 73.00	\$ 218.00	2008		TRUE	TRUE	25%		VVLT	17	EngMod
Spark Ignited Direct Injection (SIDI)	1.00%	3.00%	\$ 200.00	\$ 250.00	2008		TRUE	TRUE	3%		SIDI	18	EngMod
Engine Supercharging & Downsizing	5.00%	7.00%	\$ 364.00	\$ 582.00	2008			TRUE	25%		SUP	19	EngMod
42 Volt Electrical Systems	1.00%	2.00%	\$ 73.00	\$ 291.00	2008		TRUE	TRUE	33%		42V	20	ALR
Integrated Starter/Generator	4.00%	7.00%	\$ 218.00	\$ 364.00	2008		TRUE	TRUE	33%		ISG	21	ALR
Intake Valve Throttling	3.00%	6.00%	\$ 218.00	\$ 437.00	2010		TRUE		25%		IVT	22	EngMod
Camless Valve Actuation	5.00%	10.00%	\$ 291.00	\$ 582.00	2010			TRUE	25%		CVA	23	EngMod
Variable Compression Ratio	2.00%	6.00%	\$ 218.00	\$ 510.00	2010			TRUE	25%		VCR	24	EngMod
Advanced CVT	0.00%	2.00%	\$ 364.00	\$ 874.00	2009				25%		ACVT	25	TrMod
Dieselizeation	15.00%	20.00%	\$ 1,000.00	\$ 2,000.00	2010			TRUE	3%		DSL	26	EngMod
Material Substitution (cost in \$ per pound reduced)	0.60%	0.70%	\$ 0.75	\$ 0.75	2008	TRUE	TRUE	TRUE	20%	1.0%	MS1	27	MSM
Material Substitution (cost in \$ per pound reduced)	0.60%	0.70%	\$ 1.00	\$ 1.00	2008		TRUE	TRUE	20%	1.0%	MS2	28	MSM
Material Substitution (cost in \$ per pound reduced)	1.75%	2.10%	\$ 1.25	\$ 1.25	2008			TRUE	20%	3.0%	MS3	29	MSM
Material Substitution (cost in \$ per pound increased)	-0.60%	-0.70%	\$ 0.75	\$ 0.75	2008				20%	-1.0%	MSX	30	MSP
Midrange Hybrid Vehicle	25.00%	35.00%	\$ 3,000.00	\$ 5,000.00	2010			TRUE	3%		HEV	31	ALR

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

With respect to materials substitution, the NAS estimated that a 5 percent weight reduction could be achieved at a constant cost of \$210-350, reducing fuel consumption by 3-4%. In order to accommodate the possibility of smaller changes in materials (e.g., resulting from changes in

1 fewer and/or smaller components), and to account for the fact that constant percentage changes  
 2 in weight imply greater absolute substitution of materials and therefore greater cost for heavier  
 3 vehicles, we instead represent three levels of materials substitution as weight-reducing  
 4 technologies. The relative reduction of vehicle weight at each level is specified in the  $k_{Weight}$   
 5 column as a percentage reduction of the vehicle's current curb weight. This approach is similar  
 6 to that used by NEMS, and specifies cost in dollars per pound of reduction of vehicle weight.  
 7 We also accommodate the possibility that materials substitution could be applied to increase  
 8 vehicle weight, as doing so might appear as a logical compliance strategy under some weight-  
 9 based CAFE systems.

10  
 11 For each technology, Table C-5 contains the following:

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

27  
 28 The structures for handling fuel consumption changes, costs, and technology path are all  
 29 consistent with the NAS report. Because the NAS report considered the feasibility of higher  
 30 CAFE levels at some unspecified point in the future, it did not directly address potential  
 31 constraints on the rate at which technologies could penetrate the fleet. We have done so by  
 32 including the year available and phase-in cap mentioned above. The example shown in Table C-  
 33 5 specifies first year available of 2008 and a phase-in cap of 25% for cylinder deactivation. This  
 34 constrains the compliance simulation model discussed in Section III.B.1 such that it does not  
 35 begin considering applying cylinder deactivation until MY2007. Also, in the initial model year  
 36 that the model attempts to apply cylinder deactivation to a given manufacturer's fleet, it stops  
 37 applying the technology if it has affected at least 25% that manufacturer's fleet. In the second  
 38 year, it is allowed to apply cylinder deactivation to an additional 25%, and so on.  
 39

---

<sup>57</sup> Page 40 of the NAS report refers to these as "product development paths".

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

9  
10 For system development and testing, we have developed technology files that, for the most part,  
11 define the same technology paths and use the same cost and fuel consumption estimates as in the  
12 NAS report. For each technology, we have specified an initial year of availability and a phase-in  
13 cap based on our expectations, taking into account relevant confidential information provided by  
14 manufacturers.

15  
16 Our input assumptions for Dieselization, materials substitution, and hybridization also reflect our  
17 own expectations. Our review of MY2002 data indicates that Diesel engines typically involve a  
18 \$3,000-\$5,000 price premium and approximately a 35% reduction in the rate of fuel  
19 consumption. This is considerably higher than the NAS report's suggestion of a \$2,000-\$3,000  
20 price premium. We reduce both cost and fuel consumption benefit estimates to appropriately  
21 treat Dieselization as an incremental improvement compared to a gasoline engine to which other  
22 technologies have already been applied.

23  
24 We developed assumptions regarding the cost and effectiveness of materials substitution by  
25 considering EIA and NAS estimates. For AEO2004, EIA assumed the cost of materials  
26 substitution increases from \$0.40/pound to \$1.20/pound as the scale of weight reduction  
27 increases from 5% to 20%. The NAS report estimated a fixed cost of \$210-\$350, which is  
28 equivalent to approximately \$1.00/pound-\$2.00/pound depending on initial vehicle weight. The  
29 NAS's assumption that fuel consumption falls by about 0.6-0.8% for each 1% reduction in curb  
30 weight is similar to EIA's assumption that fuel economy increases by 0.67% for each such  
31 weight reduction.

32  
33 We developed estimates of the incremental cost and effectiveness of hybrid drivetrains by  
34 considering relevant confidential information provided by some manufacturers. Although hybrid  
35 vehicles are currently available for sale, their incremental prices do not, in our estimation,  
36 reasonably reflect their costs.

1 *Scenario Definition*

2  
3 Worksheets that begin "SCEN" are identified as CAFE program scenarios, which are defined in  
4 terms of the design and stringency of the CAFE program. The system numbers these scenarios  
5 0,1,2,... based on their order of appearance. Scenario 0 (Scen0) is identified as the baseline  
6 scenario to which all others are compared. Each scenario defines the CAFE program as it relates  
7 to the following "regulatory classes":

8  
9 **Table C-6. Regulatory Classes**

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

10  
11  
12 Under the current system, all nonpassenger automobiles with GVW ratings below 8,500 pounds  
13 will be assigned to regulatory class 3. Regulatory classes 4-10 will all be unused. For systems  
14 involving subclasses of nonpassenger automobiles, some or all of these regulatory classes will be  
15 used. By default, regulatory class 0 includes vehicles with GVW ratings above 8,500 pounds.  
16 However, as discussed below, such vehicles can be selectively assigned to nonpassenger  
17 automobile regulatory classes.

18  
19 Table C-7 shows an example of a CAFE scenario definition worksheet. The purpose of each of  
20 the named and bordered sections is as follows:

21  
22 Scenario Description: a short name describing the key features of the scenario

23 Passenger Automobile CAFE Standard: numerical standard applicable in each model  
24 year

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

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

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

38 Trading Between LT Classes: Specifying "Y" or "N" allows or disallows trading of  
39 CAFE credits between different classes of nonpassenger automobiles (but not between  
40 passenger and nonpassenger automobiles or between manufacturers). Future versions of



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

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

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

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

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

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

17

Table C-7. Scenario Definition Worksheet (Sample)

CAFE Scenario Definition Worksheet		Model Year													
Scenario Description		conventional system with 22.2 mpg light truck standard													
Passenger Automobile CAFE Standard (mpg)		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
		27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
Applicability of Light Truck Program	LT Definition	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	HLT Inclusion	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Attribute															
LT Reg. Class Boundaries: (upper boundary of attribute)  10,000 for highest class blank if not applicable	Req. Class	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	3														
	4														
	5														
	6														
	7														
	8														
	9														
	10														
	Light Truck Flat Standard Value (mpg)	Req. Class	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3		22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
4															
5															
6															
7															
8															
9															
10															
Trading Between LT Classes		Allowed?	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	Discounting														
LT Std. Functional Form (Single Class Only)		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
LT Functional Form Coefficients (ignored for multiclass systems)	Coefficient	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	A														
	B														
	C														
	D														
	E														
	F														
	G														
	H														
	I														
J															
HLT Flat Standard (mpg)		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Transitional Flat Standard (mpg)		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CAFE Fine Rate (\$/mpg-vehicle)		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
		55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0

Table C-8. Functional CAFE Standard Specifications

Type	Description	Specification
1	"Fixed attribute" system based on MY2002 curb weights A. mpg	$STD_{MY} = \frac{A \times \sum_i SALES_{i,MY} 2002}{\sum_i (SALES_{i,MY} 2002 \times CW'_{i,MY} 2002)}$
2	Logistic weight-based function A. mpg ("ceiling") B. mpg ("floor") C. pounds ("width") D. pounds ("midpoint")	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( SALES_{i,MY} \times \left[ \frac{1}{A} + \left( \frac{1}{B} - \frac{1}{A} \right) \frac{\exp\left(\frac{CW'_{i,MY} - D}{C}\right)}{1 + \exp\left(\frac{CW'_{i,MY} - D}{C}\right)} \right] \right)}$
3	Exponential weight-based function A. mpg ("ceiling") B. mpg (should be >A) C. pounds (determines "height")  note: if CWmin is the lowest possible weight, C must not exceed CWmin/(1-ln(B/A))	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( SALES_{i,MY} \times \left[ \frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{CW'_{i,MY}}{C}\right) \right] \right)}$
4	Logistic area-based function A. mpg ("ceiling") B. mpg ("floor") C. square feet ("width") D. square feet ("midpoint")	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( SALES_{i,MY} \times \left[ \frac{1}{A} + \left( \frac{1}{B} - \frac{1}{A} \right) \frac{\exp\left(\frac{AREA_{i,MY} - D}{C}\right)}{1 + \exp\left(\frac{AREA_{i,MY} - D}{C}\right)} \right] \right)}$
5	Exponential area-based function A. mpg ("ceiling") B. mpg (should be >A) C. sq. ft. (determines "height")  note: if AREAMin is the lowest possible area, C must not exceed AREAMin/(1-ln(B/A))	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( SALES_{i,MY} \times \left[ \frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{AREA_{i,MY}}{C}\right) \right] \right)}$
6	Logistic weight- and area-based function A. mpg ("ceiling") B. mpg ("floor") C. pounds ("width") D. pounds ("midpoint") E. square feet ("width") F. square feet ("midpoint")	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( SALES_{i,MY} \times \left[ \frac{1}{A} + \left( \frac{1}{B} - \frac{1}{A} \right) \frac{\exp\left(\frac{CW'_{i,MY} - D}{C}\right)}{1 + \exp\left(\frac{CW'_{i,MY} - D}{C}\right)} \right] \left[ \frac{\exp\left(\frac{AREA_{i,MY} - F}{E}\right)}{1 + \exp\left(\frac{AREA_{i,MY} - F}{E}\right)} \right] \right)}$
7	Exponential weight- and area-based function A. mpg B. mpg C. pounds D. square feet  note: select coefficients carefully	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( SALES_{i,MY} \times \left[ \frac{1}{A} - \frac{1}{B} \exp\left(1 - \frac{CW'_{i,MY}}{C} - \frac{AREA_{i,MY}}{D}\right) \right] \right)}$
8	Weight-based function with "weight efficiency" credit A. mpg B. pounds C. dimensionless D. dimensionless E. pounds per square foot F. pounds	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( \frac{SALES_{i,MY}}{A} \left( \frac{CW'_{i,MY}}{B} + C \right) \left( D - \frac{CW'_{i,MY}}{E * AREA_{i,MY} - F} \right) \right)}$
9	Harmonically averaged targets TARGET bin-specific "target" (mpg)  (involves recasting RC3+ as "bins" that all exist with RC3)	$STD_{MY} = \frac{\sum_i SALES_{i,MY}}{\sum_i \left( \frac{SALES_{i,MY}}{TARGET_{i,MY}} \right)}$

1  
2  
3

4

1  
2  
3  
4

*[page intentionally blank]*

1 *Parameters*

2  
3 The benefits model parameters file contains a variety of input data and assumptions used to  
4 estimate various impacts of the simulated response of the industry to CAFE standards. The file  
5 contains a series of worksheets, the contents of which are summarized below.

6  
7 *"General" Parameters*

8  
9 The "general" parameters worksheet contains a few input assumptions used when calculating the  
10 "effective cost" of technologies using (1.1). These include the discount rate, payback period, and  
11 fuel economy shortfall to use when calculating the value of reductions in fuel consumption.<sup>58</sup>

12  
13 **Table C-10. "General" Parameters (Sample)**

14

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

15

---

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

1 MY2002 Curb Weights

2  
 3 If a "fixed attribute" system based on MY2002 curb weights (see Table C-8) is selected (see "LT  
 4 Std. Functional Form" in Table C-7), data regarding manufacturer-specific average nonpassenger  
 5 automobile curb weights is required. The "MY02LTWeight" worksheet, shown in Table C-11,  
 6 contains this information. For those manufacturers (e.g., Daewoo, or DAE) that did not produce  
 7 nonpassenger vehicles in MY2002, the system applies the industry-wide average value of 4,329  
 8 pounds if the vehicles input files indicates that the same manufacturers will introduce such  
 9 vehicles in subsequent model years.

10  
 11  
 12

Table C-11. MY2002 Curb Weights

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

13  
 14

1 *Willingness to Pay Fines*

2

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

6

7

8

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

**Willingness to Pay CAFE Fines**

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

9

11

1 *Vehicle Age Data*

2  
3 The "Vehicle Age Data" worksheet contains age-specific (*i.e.*, vintage-specific) estimates of the  
4 survival rate and annual accumulated mileage applicable to different vehicle categories.

5  
6 **Table C-16. Vehicle Age Data**

7

Category	Model Characteristic	Units	Definition/Notes	Source
Vehicle Age Data	Survival Rate	proportion	Proportion of original vehicle sales that remain in service by vehicle age (year 0 to 25)	U.S. Environmental Protection Agency, Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage Accumulation Rates and Projected Vehicle Counts for Use in MOBILE6, EPA420-P-99-011, April 1999. <a href="http://www.epa.gov/otaq/models/mobile6/01047.pdf">http://www.epa.gov/otaq/models/mobile6/01047.pdf</a> , Appendix B, Table 4-5, p. 45
	Average Annual Miles Driven	average miles per vehicle per year	Average annual miles driven by surviving vehicles by vehicle age (year 0 to 25)	

8  
9  
10 Separate survival fractions are used for automobiles and light trucks. These measure the  
11 proportion of vehicles originally produced during a model year that remain in service at each age  
12 (up to 25 years for automobiles and 30 years for light trucks), by which time only a small  
13 fraction typically remain in service. The survival rates used in this analysis were estimated by  
14 NHTSA staff using R.L. Polk National Vehicle Population Profile data for 1999-2004, as  
15 described in *Vehicle Survivability and Travel Mileage Schedules*, Office of Regulatory Analysis  
16 and Evaluation, National Center for Statistics and Analysis, National Highway Traffic Safety  
17 Administration, January 2005.

18  
19 The measures of annual miles driven per vehicle for light-duty vehicles used in our model were  
20 estimated using equations fitted to data on estimated annual utilization of a sample of more than  
21 50,000 household vehicles obtained from the Federal Highway Administration's *2001 National*  
22 *Household Travel Survey*.<sup>62</sup> Separate estimates of average annual use at different ages were  
23 developed for automobiles and three types of light trucks: pickups, vans, and sport/utility  
24 vehicles. Light truck models are assigned the appropriate schedule of annual mileage by age.  
25

<sup>62</sup>See [http://nhts.ornl.gov/2001/html\\_files/introduction.shtml](http://nhts.ornl.gov/2001/html_files/introduction.shtml)



1 *Fuel Properties*

2  
3 The "Fuel Properties" worksheet contains estimates of the physical properties of gasoline and  
4 diesel fuel, as well as certain assumptions about the effects of reduced fuel use on different  
5 sources of petroleum feedstocks and on imports of refined fuels. These fuel properties and  
6 assumptions about the response of petroleum markets to reduced fuel use are used to calculate the  
7 changes in vehicular carbon dioxide emissions as well as in "upstream" emissions (from  
8 petroleum extraction and refining and from fuel storage and distribution) that are likely to result  
9 from reduced motor fuel use.

10  
11 **Table C-17. Fuel Properties**

12

Category	Model Characteristic	Unit	Definition/Notes	Source
Fuel Properties	Energy Density	BTU/gal	Amount of energy stored in a given system or region of space per unit volume. Varies by fuel type.	Wang, Michael, <i>The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.5 Technical Report</i> , Argonne National Laboratory, August 1999, Table 3.3, p. 25 ( <a href="http://greet.anl.gov/pdfs/esd_3v1.pdf">http://greet.anl.gov/pdfs/esd_3v1.pdf</a> ).
	Mass Density	grams/gal	Mass per unit volume. Varies by fuel type.	
	Carbon Content	percent by weight	Average share of carbon in fuel. Varies by fuel type.	
	Sulfur Content	ppm by weight	Average share of sulfur in fuel. Varies by fuel type.	
	Share of Base Case Fuel Use Imported as Refined Fuel	percent	Varies by fuel type.	Energy Information Administration, <i>Annual Energy Outlook 2003</i> , Tables 1, 2, and 117, and Volpe assumptions.
	Share of Base Case Fuel Use Refined within U.S.	percent	Varies by fuel type.	
	Share Refined from Domestic Crude	percent	Varies by fuel type.	
	Share Refined from Imported Crude	percent	Varies by fuel type.	
	Share of Fuel Savings Leading to Lower Fuel Imports	percent	Varies by fuel type.	
	Share of Fuel Savings Leading to Reduced Domestic Fuel Refining	percent	Varies by fuel type.	
	Share of Reduced Domestic Refining from Domestic Crude	percent	Varies by fuel type.	
	Share of Reduced Domestic Refining from Imported Crude	percent	Varies by fuel type.	
	Assumed Fuel Mix	percent	Estimated share of total fuel consumption by fuel type.	

13  
14  
15 Energy density, mass density, carbon content, and sulfur content for different types of gasoline  
16 and for diesel were obtained from documentation describing the development of Argonne  
17 National Laboratory's GREET vehicular energy use and emissions model.<sup>63</sup> Fuel and crude  
18 petroleum import assumptions were calculated from Energy Information Administration, *Annual*  
19 *Energy Outlook 2003*, Tables 1, 2, and 117, and Volpe assumptions developed from discussions  
20 with Department of Energy staff.

21  
22 The assumed mix of different types of gasoline used by light-duty vehicles was calculated from  
23 U.S. EPA, *Regulatory Impact Analysis for Tier 2 Emissions Standard*, Table 19, p. 42, and  
24 estimates supplied by the Ford Motor Company in comments on proposed 2005-07 Light Truck  
25 CAFE Rule. The mix of gasoline and diesel use was determined from sales volumes and fuel  
26 economy levels for light-duty vehicle models designed to operate on each fuel.

27  
<sup>63</sup> Wang, Michael, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model: Version 1.5 Technical Report*, Argonne National Laboratory, August 1999, Table 3.3, p. 25 ([http://greet.anl.gov/pdfs/esd\\_3v1.pdf](http://greet.anl.gov/pdfs/esd_3v1.pdf)).

1 *Upstream Emissions*

2  
3 The “Upstream Emissions” worksheet contains emission factors for greenhouse gas and criteria  
4 pollutant emissions from petroleum extraction and transportation, and from fuel refining, storage,  
5 and distribution. These emission factors were calculated using emission rates derived from  
6 Argonne National Laboratories’ GREET model..<sup>64</sup>

7  
8 **Table C-18. Upstream Emissions**

9

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

10  
11 *Fleet Parameters*

12  
13 The “Fleet Parameters” worksheet contains information used to assign vehicles to MOBILE6  
14 classes for purposes of estimating tailpipe emissions of criteria pollutants, and to account for the  
15 gap between test and actual on-road fuel economy when calculating changes in fuel  
16 consumption.

17  
18 **Table C-19. Fleet Parameters**

19  
20

Category	Model Characteristic	Units	Definition/Notes	Source
Fleet Parameters	% of Calendar Year, Sales that are Model Year, Vehicles	percent	THIS VALUE NOT USED IN CURRENT ANALYSIS	Volpe analysis of monthly sales patterns for new vehicles of model years 2002 and 2003 reported in Automotive News.
	% of Calendar Year, Sales that are Model Year, Vehicles	percent	THIS VALUE NOT USED IN CURRENT ANALYSIS	
	% of Calendar Year, Sales that are Model Year, Vehicles	percent	THIS VALUE NOT USED IN CURRENT ANALYSIS	
	% of Light Trucks under 6,000 lbs. GVWR consisting of MOBILE6 Class LDG11	percent	Varies by calendar year	Calculated from MOBILE6 fleet registration fractions for future calendar years
	% of Light Trucks under 6,000 lbs. GVWR consisting of MOBILE6 Class LDG12	percent	Varies by calendar year	
	% of Light Trucks under 6,000 lbs. GVWR consisting of MOBILE6 Class LDG12	percent	Varies by calendar year	
	% of Light Trucks 6,001-8,500 lbs. GVWR consisting of MOBILE6 Class LDG13	percent	Varies by calendar year	
	% of Light Trucks 6,001-8,500 lbs. GVWR consisting of MOBILE6 Class LDG14	percent	Varies by calendar year	
	% of Light Trucks 6,001-8,500 lbs. GVWR consisting of MOBILE6 Class LDG14	percent	Varies by calendar year	
	Gap between Test and On-Road MPG	percent	Adjustment to reflect the expected size of the fuel economy “gap” between test condition fuel economy performance and on-road fuel economy performance	EPA/OTAQ estimate
Average Fuel Tank Capacity	gallons	Varies by vehicle type	Volpe calculation	

21  
22  
23 Actual fuel economy levels achieved by vehicles in on-road driving falls significantly short of  
24 the level measured by U.S. EPA under test conditions. The actual fuel economy performance of  
25 each model year’s vehicles is adjusted to reflect the expected size of this fuel economy “gap” in  
26 future calendar years.

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

Economic Values

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

Table C-20. Economic Values

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

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

1 imply that increasing vehicle use will offset 10-20% of the fuel savings resulting directly from an  
2 improvement in fuel economy.<sup>65</sup>

3  
4 Our model employs the annual discount rate of 7% recommended for evaluation of proposed  
5 regulations by the White House Office of Management and Budget's Office of Information and  
6 Regulatory Affairs.

7  
8 Importing petroleum into the United States is widely believed to impose significant costs on ,  
9 households and businesses that are not reflected in the market price for imported oil, and thus are  
10 not borne by consumers of refined petroleum products. These costs include three components:  
11 (1) higher costs for oil imports resulting from the combined effect of U.S. import demand and  
12 OPEC market power on the world oil price; (2) the risk of reductions in U.S. economic output  
13 and disruption of the domestic economy caused by sudden reductions in the supply of imported  
14 oil; and (3) costs for maintaining a U.S. military presence to secure imported oil supplies from  
15 unstable regions, and for maintaining the Strategic Petroleum Reserve (SPR) to cushion against  
16 price increases. By reducing domestic demand for gasoline, tighter CAFE standards may reduce  
17 petroleum imports, thus lowering some or all of these external or social costs to the U.S.  
18 economy from importing oil.

19  
20 Empirical estimates of the first of these three components of the economic cost of importing  
21 additional petroleum into the U.S. vary widely. A detailed analysis by Leiby *et al.* (1997)  
22 estimated a range of values for this cost corresponding to approximately \$1.50-3.50 per barrel in  
23 today's terms.<sup>66</sup> Using the midpoint of this range, reducing the level of U.S. oil imports would  
24 result in "social" cost savings to the U.S. economy of approximately \$2.50 per barrel beyond the  
25 direct savings in gasoline costs. This figure is equivalent to about \$0.061 per gallon of gasoline  
26 saved as a consequence of more stringent CAFE regulation.

27  
28 Leiby *et al.* also estimate that under reasonable assumptions about the probability that import  
29 supplies will be disrupted to varying degrees in the future, the second component of the social  
30 cost of oil imports ranges from slightly under \$1.00 to approximately \$3.00 per additional barrel  
31 of oil imported by the U.S. Within this range, an estimate of approximately \$2.00 per barrel  
32 seems most appropriate, which implies that reductions in the level of oil imports resulting from  
33 tighter light truck CAFE standards would reduce disruption costs by about \$0.045 per gallon of  
34 gasoline saved. This and other studies argue that the cost of maintaining a U.S. military presence

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

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

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

5  
6 Our analysis uses the Federal Highway Administration's estimates of the costs of the incremental  
7 (or "marginal") costs of added traffic congestion, accidents, and vehicle noise resulting from  
8 increased vehicle travel to estimate the increased external costs caused by added light truck use  
9 resulting from the rebound effect.<sup>67</sup> These estimates incorporate adjustments of current or  
10 baseline congestion and accident costs that are intended to reflect the traffic conditions under  
11 which additional driving is likely to take place, as well as its likely effects on both the frequency  
12 and severity of motor vehicle accidents. The FHWA estimates of these costs agree closely with  
13 other recent estimates of external costs from light-duty vehicle use.<sup>68</sup>

14  
15 Estimates of damage costs for criteria pollutant emissions estimates were derived by the White  
16 House Office of Management and Budget's Office of Information and Regulatory Affairs from  
17 values used in recent U.S. EPA analyses of regulations intended to reduce various sources of  
18 these emissions.<sup>69</sup> Our model employs these estimates to calculate the increased health and  
19 property damage costs caused by added emissions of air pollutants and their chemical precursors  
20 resulting from "rebound effect" travel. Because of the extremely wide range of estimates for both  
21 damage and control costs for carbon emissions that have been reported in recent research, we do  
22 not not attempt to estimate an economic value for reductions in carbon emissions from  
23 gasoline refining or use.

24  
25 We assume that each refueling cycle requires 10 minutes, and we apply the current U.S. DOT  
26 estimates of the value of travel time and average vehicle occupancy to estimate the value of the  
27 annual time savings to drivers and passengers resulting from less frequent refueling. These  
28 values are reported in *The Value of Travel Time: Departmental Guidance for Conducting*  
29 *Economic Evaluations*, Office of the Assistant Secretary for Transportation Policy, April 9,  
30 1997, and *Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis*,  
31 Office of the Assistant Secretary for Transportation Policy, February 11, 2003.<sup>70</sup>

### 32 33 *Forecast Data*

34  
35 The "Forecast Data" worksheet contains exogenous forecasts of total long-term automobile and  
36 light truck sales. It also contains estimates of future fuel prices, which are used when calculating  
37 pre-tax fuel outlays and fuel tax revenues.

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

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

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

<sup>70</sup> See <http://ostpxweb.dot.gov/reports>.

1  
2  
3

Table C-21. Forecast Data

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

4  
5

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

10

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

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

<sup>72</sup> U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2005*, Table 12,  
[http://www.eia.doe.gov/oiaf/aeo/excel/acotab\\_12.xls](http://www.eia.doe.gov/oiaf/aeo/excel/acotab_12.xls)

<sup>73</sup> Federal Highway Administration, Highway Statistics 2003, Table MF121T,  
<http://www.fhwa.dot.gov/policy/ohim/hs03/htm/mf121t.htm>

*Vehicular Criteria Pollutant Emission Factors*

Emission factors (all in grams per mile and specific to both vehicle model year and age) for three fuel types (gasoline, reformulated gasoline, and Diesel) and five pollutants (CO, VOC, NO<sub>x</sub>, PM<sub>2.5</sub>, and SO<sub>2</sub>) are contained in a series of fifteen worksheets of identical structure.

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

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

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

The pollutants we considered included carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and fine particulate matter (PM<sub>2.5</sub>, or particulate matter less than 2.5 microns in diameter). Particulate matter includes sulfate particulates, elemental carbon, non-volatile organic carbon compounds, and airborne lead, as well as particulate emissions from brake and tire wear. Because we are concerned with increased emissions from more intensive use of existing vehicles (rather than from a larger vehicle fleet),

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

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

6  
7 We estimated emission factors separately for gasoline-powered automobiles (MOBILE6 vehicle  
8 class 1), diesel automobiles (class 14), gasoline trucks under 6,000 pounds GVWR (classes 2 and  
9 3), gasoline trucks from 6,000-8,500 pounds GVWR (classes 4 and 5), gasoline trucks from  
10 8,500-10,000 GVWR (class 6), and diesel trucks of each of these same weight classes (classes  
11 15, 28, and 16). We developed composite emission factors for gasoline trucks from 6,000-8,500  
12 pounds GVWR and from 8,500-10,000 GVWR using weighted averages of the two sub-classes  
13 of trucks in those weight ranges (classes 2 and 3 and classes 4 and 5 respectively), using as  
14 weights MOBILE6's estimates of the fraction of the U.S. vehicle fleet that will be comprised of  
15 each of these sub-classes during each year from 2005-30.

16  
17 We attempted to estimate emission factors that would be representative of those for added  
18 vehicle use distributed throughout the U.S. and over times of the day similarly to current  
19 aggregate vehicle use. Because carbon monoxide accumulations are a more serious problem  
20 during winter months, we estimated CO emission factors for the month of January, assuming  
21 typical daily temperatures in more northerly states. Emission factors for other pollutants were  
22 estimated for July, assuming a daily temperature range of 65 to 90 degrees. Default values for  
23 factors affecting emissions such as the mix of travel by roadway type, travel speeds, variation in  
24 trip-making activity over the day, the distribution of trip lengths, altitude, and humidity were  
25 assumed. Most of these assumptions tend to produce "worst case" estimates of the contribution  
26 to air pollutant concentrations from added rebound-effect driving.



1 **Appendix D. Outputs**

2  
3 *Overview*

4  
5 The system produces up to four formatted output files, all as Microsoft Excel workbooks, for  
6 each scenario defined in the compliance model parameters file. The system uses folders (*e.g.*,  
7 Scenario\_0, Scenario\_1,...) to organize these files. Table D-1 lists the available output files and  
8 their contents. As discussed earlier, the first scenario appearing in the compliance model  
9 parameters file is assigned to Scenario 0 and treated as the baseline scenario. Output files for all  
10 other scenarios report absolute and relative changes compared to this baseline.<sup>76</sup>

11 **Table D-1. Output File Contents**

12  
13

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

14

<sup>76</sup> For example, if the baseline scenario involves a flat 22.2 mpg standard for nonpassenger automobiles and Scenario 1 examines a 22.5 mpg standard, Industry\_Summary\_Sn1.xls might report total technology costs of \$2.5b, of which only \$0.4b might be attributable to the increase from 22.2 to 22.5 mpg.

<sup>77</sup> Here, the asterisk (\*) indicates a number corresponding to a scenario, with 0 indicating the baseline scenario.

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

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

8

9 To protect confidential business information and otherwise protected information, the file  
10 defining the initial state of the fleet for this example—*demo\_market\_data.xls*—contains  
11 fictitious data. Therefore, when used with this file, the system will produce  
12 fictitious results. Though useful for diagnostic purposes, such results should be treated as  
13 otherwise meaningless, and should not be cited or released.

Industry-Level Summary

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

Model Years		2002 Total		
		Current Scenario	Delta (abs.)	Delta (%)
Total Sales	RC 0	28,704	-213	(1%)
	RC 1	4,584,281	-54,411	(1%)
	RC 2	3,615,042	-17,702	(0%)
	RC 3	7,940,496	72,326	1%
	LT Overall	7,940,496	72,326	1%
	Overall	16,168,523	0	(0%)
Average Fuel Economy	RC 0	19.35	0.34	2%
	RC 1	28.32	0.03	0%
	RC 2	29.03	0.02	0%
	RC 3	22.38	1.33	6%
	LT Overall	22.38	1.33	6%
	Overall	25.16	0.63	3%
Average Curb Weight (lb.)	RC 0	4,857	-1	(0%)
	RC 1	3,180	0	0%
	RC 2	3,136	0	0%
	RC 3	4,336	4	0%
	LT Overall	4,336	4	0%
	Overall	3,741	7	0%
Average Area (sq. ft.)	RC 0	117	0	(0%)
	RC 1	94	0	0%
	RC 2	86	0	0%
	RC 3	103	0	0%
	LT Overall	103	0	0%
	Overall	97	0	0%
Average Technology Costs (RPE)	RC 0	\$ 164.03	\$ 52.70	47%
	RC 1	\$ 15.02	\$ 3.17	27%
	RC 2	\$ 15.98	\$ 1.95	14%
	RC 3	\$ 300.98	\$ 224.90	296%
	LT Overall	\$ 300.98	\$ 224.90	296%
	Overall	\$ 155.94	\$ 112.17	256%
Average Fines Incurred (RPE)	RC 0	\$ -	\$ -	-%
	RC 1	\$ -	\$ -	-%
	RC 2	\$ 4.48	\$ (0.03)	(1%)
	RC 3	\$ 0.47	\$ 0.47	27310%
	LT Overall	\$ 0.47	\$ 0.47	27310%
	Overall	\$ 1.23	\$ 0.22	22%
Average Price Increase Per Vehicle (Including Tech Costs and Fines)	RC 0	\$ 247.19	\$ 148.66	151%
	RC 1	\$ 229.27	\$ 158.21	223%
	RC 2	\$ 50.91	\$ 36.30	249%
	RC 3	\$ 163.59	\$ 120.56	280%
	LT Overall	\$ 163.59	\$ 120.56	280%
	Overall	\$ 157.17	\$ 112.38	251%
Total Incurred Technology Costs (\$m)	RC 0	\$ 4.71	\$ 1.49	46%
	RC 1	\$ 68.84	\$ 13.90	25%
	RC 2	\$ 57.79	\$ 6.82	13%
	RC 3	\$ 2,389.95	\$ 1,791.35	299%
	LT Overall	\$ 2,389.95	\$ 1,791.35	299%
	Overall	\$ 2,521.29	\$ 1,813.55	256%
Total Fines Owed (\$m)	RC 0	\$ -	\$ -	-%
	RC 1	\$ -	\$ -	-%
	RC 2	\$ 16.21	\$ (0.17)	(1%)
	RC 3	\$ 3.74	\$ 3.72	27562%
	LT Overall	\$ 3.74	\$ 3.72	27562%
	Overall	\$ 19.95	\$ 3.55	22%
Total Increase in Sales Revenue (\$m)	RC 0	\$ 7.10	\$ 4.25	149%
	RC 1	\$ 1,051.06	\$ 721.40	219%
	RC 2	\$ 184.05	\$ 130.98	247%
	RC 3	\$ 1,298.98	\$ 960.41	284%
	LT Overall	\$ 1,298.98	\$ 960.41	284%
	Overall	\$ 2,541.18	\$ 1,817.04	251%

1 *Manufacturer-Level Summary*

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3  
4

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

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

5

1 *Vehicle-Level Summary*

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3  
4

Table D-4. Vehicle-Level Summary Contents

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

5

1 *Effects Summary*

2  
 3 The summary of effects for each scenario is organized into sections. The second section, shown  
 4 by example in Table D-6, presents calculated levels of fuel consumed (in thousands of gallons)  
 5 during the full useful life of all vehicles sold in each model year. Calculated sales volumes, full  
 6 useful life travel, and average fuel economy levels are also presented to provide a basis for  
 7 comparison. However, because the system calculates lifetime travel (taking into account the  
 8 rebound effect) and fuel consumption on a model-by-model basis, these additional aggregate  
 9 calculations are only generally explanatory, and cannot be used to calculate lifetime fuel  
 10 consumption.

11  
 12 **Table D-6. Effects Summary—Energy Consumption**

13

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

14  
 15  
 16 The third section presents estimates of full fuel cycle carbon dioxide and criteria pollutant  
 17 emissions, reporting results for the following emissions classes represented in EPA's MOBILE6  
 18 emissions model:

19  
 20 **Table D-7. MOBILE6 Emissions Classes**

21

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

22  
 23 Table D-8 shows sample emissions calculations. As indicated, carbon dioxide emissions are  
 24 reported in thousand metric tons of carbon-equivalent emissions (one metric ton of carbon  
 25 dioxide is equivalent to 12/44 of a metric ton of carbon), and all criteria pollutants are reported in  
 26 short tons (one ton equals 2,000 pounds).

Table D-8. Effects Summary—Emissions

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

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

4  
5 Pretax Fuel Expenditures: savings in pretax cost to vehicle users of vehicle fuel

6 Fuel Tax Revenues: reduction in total (federal and state) fuel tax revenues

7 Travel Value: the value derived from additional driving due to the "rebound effect"

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

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

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

13 Accident Costs: additional injury and damage costs of highway crashes

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

16  
17 In all cases, these costs and benefits are calculated for the fleet of vehicles sold in each model  
18 year over their full useful lives, discounted using the rate specified in the benefits model  
19 parameters file, and reported in thousands of constant year-2003 dollars.<sup>79</sup> Section III.C.6 of the  
20 primary text discusses these types of costs and benefits in greater detail, and Appendix C  
21 (Benefits Model Parameters) discusses corresponding input assumptions.

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<sup>79</sup> Undiscounted values of these impacts are also reported.



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

Undiscounted Owner and Societal Costs (k \$)			
Total Lifetime Pretax Fuel Expenditures	150,454,238	-4,869,397	(3%)
Fuel Tax Revenues	62,179,342	-2,018,015	(3%)
Travel Value	0	0	0%
Refueling Time Value	0	0	0%
Petroleum Market Externalities	26,378,093	-252,844	(1%)
Congestion Costs	99,527,058	395,397	0%
Noise Costs	1,492,906	5,931	0%
Accident Costs	53,495,793	212,526	0%
CO2	1,436,957	-37,398	(3%)
CO	840,065	3,176	0%
VOC	1,663,410	3,041	0%
NOX	1,646,460	2,105	0%
PM	543,963	-3,441	(1%)
SOX	996,575	-20,084	(2%)
[for future use]			
Discounted Owner and Societal Costs (k \$)			
Total Lifetime Pretax Fuel Expenditures	101,395,827	-3,316,706	(3%)
Fuel Tax Revenues	42,980,818	-1,408,383	(3%)
Travel Value	0	0	0%
Refueling Time Value	0	0	0%
Petroleum Market Externalities	15,804,285	-151,490	(1%)
Congestion Costs	60,807,783	253,897	0%
Noise Costs	912,117	3,808	0%
Accident Costs	32,684,183	136,470	0%
CO2	872,541	-22,977	(3%)
CO	429,884	1,653	0%
VOC	796,949	886	0%
NOX	805,488	205	0%
PM	331,737	-2,075	(1%)
SOX	606,525	-12,319	(2%)
[for future use]			

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