RATING THE ENVIRONMENTAL IMPACTS OF MOTOR VEHICLES: *ACEEE'S GREEN BOOK*® METHODOLOGY, 2004 EDITION

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August 2004

Report Number T041

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Rating the Environmental Impacts of Motor Vehicles:
***ACEEE's Green Book*® Methodology, 2004 Edition**
Washington, D.C.: American Council for an Energy-Efficient Economy, August 2004
Transportation Program, ACEEE Report T041

The following document is an update of the ACEEE report, "Rating the Environmental Impacts of Motor Vehicles: *ACEEE's Green Book*® Methodology, 2002 Edition," by John DeCicco and James Kliesch.

ACEEE's Green Book®: The Environmental Guide to Cars and Trucks is a consumer-oriented publication that provides comprehensive environmental ratings for cars, vans, pickups, and sport utility vehicles, enabling consumers to comparison shop with the environment in mind. Each model is given a Green Score that accounts for both health-damaging air pollutants and climate-threatening greenhouse gas emissions. This technical report documents the methodology used to develop the ratings published in the 2004 edition of *ACEEE's Green Book*®, available online at www.GreenerCars.com.

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Previous editions of *ACEEE's Green Book*® (model years 1998 through 2003) are also available for ordering. A publications catalog is available upon request.

The American Council for an Energy-Efficient Economy (ACEEE) is an independent, nonprofit research group dedicated to advancing energy efficiency as a means of environmental protection and economic development.

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ABSTRACT

Consumer education and other market-oriented approaches to improving the environmental performance of automobiles require information that is easy to understand and readily accessible. Such information can influence both buyer decisions and manufacturers' technology and product planning activities. To provide such information, ACEEE publishes *ACEEE's Green Book®: The Environmental Guide to Cars and Trucks,* an annual consumer-oriented guide providing environmental rating information for every new model in the U.S. light-duty vehicle market.

The environmental rating methodology for *ACEEE's Green Book*® is based on principles of life cycle assessment and environmental economics. The method is designed to be applicable given the limitations of data available by make and model in the U.S. market. The approach combines the impacts of traditionally regulated (criteria) pollutants with those of greenhouse gas emissions, covering both the vehicle life cycle and the fuel cycle, using a mass-based characterization of vehicle manufacturing impacts. This report covers the data issues, key assumptions, and analysis methods used to develop ACEEE's vehicle ratings. It summarizes the application of the methodology to the 2004 model year (MY), highlighting results for major classes and technology types, and identifies research needs for updating and refining the methodology. Appendices detail the parameters used to evaluate vehicles and document updates to the methodology since its original release in 1998.

INTRODUCTION

Public information and consumer education are important components of an overall strategy to address the environmental impacts of motor vehicles. Accessible information that rates car and light truck environmental performance can enable consumers to account for the environment in their purchasing decisions, help guide fleet programs and other market-creation initiatives, and assist automakers' efforts to market "greener" products.

To address these informational needs, since 1998 ACEEE has published an annual, consumer-oriented guide, now titled *ACEEE's Green Book®: The Environmental Guide to Cars and Trucks*, providing model-specific environmental information for the U.S. automotive market. This report covers the data issues, key assumptions, and analysis methods used to develop the ratings used in the model year 2004 edition of *ACEEE's Green Book®*, available online at www.GreenerCars.com. It summarizes the application of the methodology to the 2004 model year, highlights results for major classes and technology types, and identifies research needs for updating and refining the methodology. For background on the original development of this rating system and its policy context, see DeCicco and Thomas (1999b).

RATING DESIGN CONSIDERATIONS

The production, use, and disposal of an automobile affect the environment in numerous ways. Impacts start with the extraction of raw materials that go into a vehicle and continue throughout materials conversion and fabrication processes, which involve many different industries. While a vehicle is in use, fuel consumption, driving, storage, and maintenance create air, water, and noise pollution as well as greenhouse gas (GHG) emissions. Disposal of worn parts (tires, batteries, motor oil, etc.) occurs throughout a vehicle's life. Finally the vehicle itself is discarded. Steel and other components can be, and increasingly are, reclaimed and recycled, but none of these processes are impact-free. An ideal rating system would incorporate all environmental impacts over a vehicle's life cycle.

Life cycle assessment (LCA) techniques provide a framework for systematically considering environmental impacts and have been used for eco-labeling of other products (EPA 1993a, 1993b). Table 1 illustrates the range of environmental concerns to be considered over the phases of a vehicle's life cycle in the form of a product assessment matrix. Letter codes in the matrix cells show items covered in the methodology described here. Only the use phase is well covered because of the data limitations encountered when attempting to develop vehicle model-specific assessments.

Use phase energy- and air pollution-related effects do represent a substantial part of an automobile's life cycle impacts. Roughly 90% of an average vehicle's life cycle energy use occurs during its operation (Keoleian et al. 1997, Table 7.1). DeLuchi (1991) estimates that the full fuel cycle GHG emissions of a gasoline-powered automobile are 68% from fuel end use, 21% from fuel production and distribution, and 11% from vehicle materials and manufacturing processes. Thus, vehicle use accounts for 68% + 21% = 89%, closely matching the life cycle energy use share as expected. Use phase shares vary for other pollutants, being clearly high for carbon monoxide (CO) but lower for sulfur dioxide (SO_2). Moreover, use phase energy and air pollution impacts are the focus of the vehicle-oriented public policies that our rating system is intended to complement.

At present, only three types of relevant, independently verifiable data cover all makes and models: (1) vehicle emissions data, addressing most aspects of use phase air pollution; (2) vehicle fuel consumption data, addressing other aspects of use phase air pollution as well as energy use and GHG emissions; and (3) vehicle mass data, addressing materials production and manufacturing impacts. A rating system must integrate these data along with parameters for weighting the various items in order to provide a model-specific index of life cycle environmental impact.

Vehicle Emissions

Automotive emissions of criteria air pollutants and their precursors are an important cause of environmental damage. These emissions occur at the tailpipe and from fuel evaporation and leakage. In the United States, new vehicles are required to meet emissions standards that regulate CO, hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM), among other pollutants. (Until model year 2004, PM standards were enforced only for diesel vehicles, since gasoline vehicles have been considered to have negligible PM emissions.) Standardized emissions tests involve placing a vehicle on a chassis dynamometer and operating it over a simulated driving cycle while collecting samples of the exhaust. Tests are also made to detect fuel vapor leaks (evaporative emissions). Testing is the responsibility of automakers, who report the results to the U.S. Environmental Protection Agency (EPA) or the California Air Resources Board (CARB).

Standard emissions tests tend to significantly underpredict in-use emissions. Past data have revealed that lifetime average in-use emissions are two to four times higher than the nominal emissions standard levels in grams per mile (g/mi) to which the vehicles are certified (Calvert et al. 1993; Ross et al. 1995). The reliability of its emissions control system (ECS), including engine operation which affects ECS performance, is a key determinant of a vehicle's lifetime real-world emissions. EPA's mobile source emissions models incorporate degradation factors and other parameters to predict average emissions rates over vehicle lifetimes. As discussed below, our tailpipe emissions estimates for model year 2004 gasoline and diesel vehicles are largely determined through use of EPA's MOBILE6.2 model (EPA 2003a). These tailpipe emissions estimates are broadly consistent with lifetime average predictions noted by independent analysts such as Ross and Wenzel (1998). Nevertheless, substantial uncertainties remain, which is why Table 1 shows a "B" status for use-phase air pollution.

In the Fall of 2000, EPA posted its own "Green Vehicle Guide" providing car and light truck emissions ratings information on the web (www.epa.gov/greenvehicles). While the *Green Book* ratings are derived from the same source data as EPA's ratings, there are a number of technical differences. Our approach is life cycle-based; EPA's is based separately on tailpipe emissions and fuel economy, which are dominant aspects of a vehicle's life cycle impact. The *Green Book* ratings weight various regulated pollutants using factors tied to public health epidemiological findings, while EPA explicitly includes only HC and NO_x, and combines these as a simple sum. *Green Book* ratings are adjusted for in-use emissions performance, while

EPA's are not. (This issue particularly affects the relative rankings of alternative vehicles, as when comparing a compressed natural gas ultra-low emission vehicle [CNG ULEV] to a gasoline ULEV.) Furthermore, the *Green Book* utilizes a different approach to presentation of results.

Fuel Consumption

Vehicle fuel consumption and the fuel supply cycle produce emissions of both GHGs and criteria pollutants. These impacts are essentially proportional to the quantity of fuel consumed. Estimates of fuel economy (miles per gallon, or MPG) are derived from the same simulated driving tests as used for meeting emissions standards. Vehicles are labeled for fuel economy (separately for typical city and highway driving) based on these results. Procedures also exist to rate vehicles powered by electricity or other alternative fuels, which are labeled for fuel consumption as well as emissions (FTC 1996).

A vehicle's rate of fuel consumption drives its fuel cycle impacts, which vary depending on the fuel and its source. For example, grid-connected electric vehicles, which may have zero vehicle emissions, entail a variety of powerplant emissions and other impacts depending on how the electricity is generated. Emissions factors (e.g., in grams of pollutant per British thermal unit [Btu] of fuel consumed) for GHG and criteria emissions are fairly well known, based on national statistics. Thus, given fuel economy data, estimating a vehicle's fuel cycle impacts is straightforward and reliable for accurately discriminating among different models.

Manufacturing Impacts

Manufacturing impacts depend on materials use, where and how a vehicle and its components are built, and the environmental standards followed at each stage of the process. Automobile manufacturing involves a complex and fluid global supply chain, making it difficult to track the environmental pedigree of parts and materials. Impacts also depend on recycled content, since increasing the use of recycled materials can decrease impacts associated with virgin materials processing and product disposal. Data on manufacturing impacts and recycled content are not systematically available and the environmental reporting needed to provide meaningful estimates by make and model is largely undeveloped.

Given these data limitations, environmental impacts of the materials production and manufacturing phases of vehicle life are best estimated in proportion to vehicle mass. Vehicle mass also is probably a good surrogate for end-of-life impacts, although we did not attempt to incorporate environmental statistics from this final phase of the life cycle. Developing better methods for rating vehicles according to environment impacts from assembly, parts production, and materials use remains an area for future work.

INTEGRATING METHODOLOGY

In essence, our rating system is based on performing a limited LCA for each car and light truck on the market. To formalize it and reduce the results to a single metric applicable to any vehicle, we define an *environmental damage index* (EDX). We define this index as a sum of damage functions, each based on attributes associated with the life cycle of the vehicle and its fuel:

$$\text{EDX} = \Sigma_i \text{ Damage}(\text{Impact}_i)$$

In principle, impacts could include any of those listed in Table 1. A valuation based on environmental economics would use monetized damage functions so that the EDX expresses an expected life cycle environmental cost of the vehicle. We have adopted such a framework while noting its limitations. Dollar-based damage functions can never capture the full value to society of human life, health, and quality of life; ecological effects; and the moral dimensions of environmental harms.

That being said, and restricting the damages considered to GHG and criteria pollution emissions during the vehicle's life cycle and associated fuel cycle, a monetized environmental damage function reduces to:

$$\text{EDX} = \Sigma\ d_{ij}e_{ij}$$

where i is an index over emission species (air pollutants, including greenhouse gases), j is an index over locations of emissions, d_{ij} is an environmental damage cost (e.g., dollars per kilogram [$/kg]), and e_{ij} is the quantity of emissions averaged over a vehicle's operational life (e.g., grams per mile [g/mi]). The damage index so defined represents environmental impacts averaged over vehicle lifetime travel distance and the units can be given in cents per vehicle mile (¢/mi).

COMPUTER MODELING TECHNIQUES

Methods used in previous years to derive vehicle emission factors proved insufficiently robust to handle models meeting the range of standards under the Tier 2 and LEV II regulatory schemes. As a result, MOBILE6.2 (EPA 2003a), a software application developed by EPA to provide estimates of current and future motor vehicle emissions, was used as the foundation of a new set of emission factors developed for model year 2004. Although MOBILE6 is designed primarily for computation of aggregate emissions of vehicle fleets, proper management of MOBILE6 input files can yield emission factors of single vehicles meeting specific standards.

A total of 104 MOBILE6 input files were coded and run to acquire emissions estimates of vehicles meeting the various combinations of emission standard, vehicle class, and operating fuel. Primary input variables to the model include vehicle emission standard[1], operating fuel characteristics, and season; primary MOBILE6 outputs are starting and running CO, HC, and NO_x emission factors reflecting vehicle age and vehicle class. Additionally, annual VMT (by age) is acquired from the model for post-model calculations as described below.

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[1] Due to the operational structure of MOBILE6.2, the programming of specific emission standards required the inclusion of supplemental data files generated by the author and confirmed by MOBILE modeling experts at EPA and FHWA. For the sake of brevity (and readability), detailed specifics about coding of the MOBILE6.2 runs will not be included in this report. For more information on that topic, contact the author.

In general, each set of emission factors is computed through six MOBILE6 runs: a winter and summer run for each of the conventional gasoline, RFG North, and RFG South scenarios. The results of each of the runs are averaged equally, resulting in a composite emission factor for each vehicle class and emission standard. Sulfur levels used in the modeling are, with the exceptions noted below, MOBILE6 default sulfur levels indicative of expected compliance with a national sulfur phase-down.

Low-sulfur fuel modeling was also used to address a modeling anomaly related to sulfur hypersensitivity. MOBILE6 runs conducted using default sulfur levels resulted in emissions estimates for LDVs and LDT1s higher than for larger vehicle classes (Brzezinski 2003; EPA 2001d). To address this, runs of the vehicle scenarios were also conducted with sulfur set to the model's minimum level to eliminate the effect of the assumptions related to the sulfur hypersensitivity. The ratio of LDVs and LDT1s to LDT2s under the minimum-sulfur scenario were used in conjunction with LDT2 emissions modeled under the default sulfur phase-down scenarios to estimate lifetime emissions of LDVs and LDT1s operating on default sulfur levels.

The output of each MOBILE6 run, a set of factors detailing in-use emissions of CO, HC, and NO_x for each vehicle class (by year, over the course of its 25-year lifetime), were subsequently processed to determine a VMT- and survival rate-weighted lifetime average emissions rate estimate for each emission standard, vehicle class, and pollutant.

In certain circumstances, the MOBILE6 structure and/or underlying assumptions built into the model prevent its use in generating specific emission factors. For example, diesel- and CNG-fueled vehicles, when modeled on a single-vehicle basis through MOBILE6, yield implausible results. Alternate methodologies have been developed to handle these cases on an individual basis, as described in the sections below.

CHARACTERIZATION OF IMPACTS

Given the data availability as noted above, the relation $EDX = \Sigma\, d_{ij}e_{ij}$ can be calculated on the basis of vehicle emissions, fuel cycle emissions, and emissions factors based on vehicle mass (for embodied energy and environmental impacts).

VEHICLE EMISSIONS

Some vehicle emissions are regulated and others are not. We estimate both. Regulated emissions include CO, non-methane organic gases (NMOG), HC, NO_x and particulate matter smaller than 10 microns (PM_{10}). These emissions depend largely on the emissions standard to which a vehicle is certified and its fuel. Hydrocarbon vapors, also termed volatile organic compounds (VOC), are regulated according to particular definitions, such as NMOG defined in terms of photochemical reactivity. We model evaporative HC emissions as a function of both fuel consumption and emissions certification level. We estimate unregulated pollutants as a function of fuel type and consumption rate, independently of the emissions standard. The pollutants that are not directly regulated for motor vehicles but are incorporated in our rating system are SO_2, methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2).

Regulated In-Use Emissions from Vehicles up to 8,500 lb. GVW

Tailpipe and evaporative emissions are regulated for cars and light trucks under both Federal and California vehicle emissions programs. We treat regulated tailpipe emissions as depending only on the emissions standard level to which a vehicle is certified, rather than on the particular test values submitted for certification. Emissions certification is designed as a pass/fail test, and manufacturers do not have legal requirements to maintain the test values they submit, only the standard levels to which they certify. Substantial variability can exist among test results for the same model vehicle and the number of tests on each model is very low. Therefore, we do not use certification test values as a basis for our estimates. Rather, we derive estimates based on published analyses of in-use emissions data, which are not model-specific. Emissions standard levels for each pollutant (CO, HC, NO_x, and PM_{10}) are adjusted to reflect expected in-use performance over a vehicle lifetime (not just the specified mileage durability requirements over the simulated test cycles that are required for certification). The resulting in-use estimates are illustrated in Figure 1 for some of the principal standards in effect in 2004. The detailed assumptions for estimated in-use emissions for each emissions standard are presented in a multi-part table (Appendix Table A1).

Supplemental Federal Test Procedure. The Supplemental Federal Test Procedure (SFTP) was introduced in 2001 to address shortcomings with the preexisting Federal Test Procedure (FTP), including a lack of (among other driving patterns) high speed/acceleration, rapid speed fluctuation, and air conditioning use (Federal Register 1996). Methodologically, incorporation of the SFTP into the *Green Book* necessitated modest reductions of our in-use emission factors for gasoline vehicles. The SFTP program completed its legislated phase-in schedule in model year 2004, and thus all MY2004 vehicles are computed as being SFTP-compliant.

The MOBILE6 emissions modeling tool (EPA 2003a) accounts for in-use carbon monoxide, hydrocarbon, and nitrogen oxide emissions reductions resulting from the Supplemental Federal Test Procedure. These numbers include adjustments for control improvement-related emissions reductions, as well as a modest CO increase due to air conditioning loading.

For diesel vehicles, the SFTP final rule provided only a US06 off-cycle control requirement for LDV and LDT1 and exempted LDT2-4 light trucks for lack of data. The SFTP final rule also exempted diesels from the supplemental air conditioning test. While we acknowledge the large uncertainty regarding light-duty diesel in-use emissions, the absence of data suggests caution. Therefore, we do not incorporate a SFTP-related component in our diesel analysis, which is described below under *Diesel Emissions*.

Addressing gasoline characteristics. The two most significant gasoline characteristics impacting tailpipe emissions are gasoline sulfur content and reformulation.

Sulfur level. The characterization of NO_x emissions in terms of fuel sulfur is among the more critical judgments made for our methodology, since NO_x is weighted much more heavily than HC and CO in determining a vehicle's EDX (see Tables 4 and 5 for emissions damage cost estimates). The NO_x-sulfur sensitivity depends on the particular catalyst formulations, which vary with make and model. Public data are not available to discriminate by catalyst, so consistent with our overall approach, we estimate emissions based only on the standard to which a vehicle is certified.

California certified vehicles are designed to run on low sulfur fuel, ideally California Phase 2 reformulated gasoline (RFG), which is restricted to 30 parts per million (ppm) or less of sulfur. However, low-emission vehicles available nationwide are run on different fuels, including fuels with much higher sulfur levels. As of 1999, the average sulfur level in national fuel was about 330 ppm. The Tier 2 rule will greatly reduce sulfur content in gasoline, targeting an average of 30 ppm by 2006 (Federal Register 2000). Since we characterize emissions over the entire vehicle lifetime, it is appropriate to evaluate vehicles dynamically at expected sulfur levels over that time period.

MOBILE6 emissions model input parameters include a default phase-down of "average" and "maximum" sulfur levels between 2004 and 2008 (with constant 30 ppm average levels thereafter)[1], facilitating dynamic modeling of a gasoline sulfur reduction. These input parameters are used for all vehicles certified to standards with wide geographic availability. Some models, however, are being sold exclusively in states that have adopted the California emissions control program (California, Maine, Massachusetts, New York, and Vermont in MY2004), and/or where low sulfur gasoline is widely available. Based on an analysis of the MY2004 fleet, these models were deemed to be gasoline LEV II-SULEV and PZEV-certified vehicles. Such vehicles are modeled as being driven on low-sulfur (30 ppm) fuel for the duration of their lives.

Reformulated gasoline. This year, we modeled HC, CO, and NO_x emissions estimates with MOBILE6 emissions modeling software developed at EPA. In calculating tailpipe emissions, the MOBILE6 model allows the user to model the use of both conventional gasoline and RFG; the latter is expected to account for 33% of gasoline consumption for all years between 2000 and 2020 (DOE 1999). In order to approximate a national emissions estimate, we calculate both RFG and conventional gasoline emission rates, and then average these values to approximate consumption of all gasoline.

Incorporation of VMT and Survival Rates. As documented in DeCicco and Kliesch (2002), emission rates as a function of mileage for each pollutant have previously been calculated from a zero-mile rate, two deterioration rates, and a point of inflection between the two deterioration rates. Lifetime average emission rates were determined by integrating the function, assuming an average vehicle lifetime of 120,000 miles.

After consultation with members of EPA and Oak Ridge National Laboratory (ORNL), we decided to incorporate VMT variation and survival information into our methodology. This change reflects the notion that cars and light trucks are driven more during the earlier portion of their lives, when deterioration rates are lower. Fleet characterization data for passenger cars and trucks, documented in EPA (2001a) and specified in the MOBILE6 model output, is used in conjunction with recent car and light truck survival data (Davis and Diegel 2002) to produce a normalized "survival mile" data set for each vehicle class between LDV and LDT4. Table 8 shows the resulting survival miles (as a percentage of lifetime travel) over the assumed 25-year

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[1] For specific sulfur levels year-by-year, see EPA (2002); section 2.8.10.1.

lifetime. These percentages are then used as weights by which emission factors for each of the pollutants (by age) are applied to estimate lifetime average emissions levels.

CO, HC, and NO$_x$ emissions characterization. As mentioned above, the MOBILE6 emissions model can be programmed to provide CO, HC, and NO$_x$ emissions characterizations for individual classes of vehicles meeting specified emissions certification and fuel parameter criteria. Lifetime average CO, HC, and NO$_x$ in-use emission factors were generated by writing and executing over one-hundred MOBILE6 input files, and performing post-calculations on the model's output files. Because MOBILE6 is designed primarily to generate emissions estimates for groups of vehicles (rather than a single vehicle), new vehicle data (".d") files were created to allow for the computation of single vehicle emission factors. Primary MOBILE6 input variables relevant to gasoline vehicle CO, HC, and NO$_x$ emission characterization include vehicle class, emissions standard, season, fuel type, fuel sulfur content, and Inspection and Maintenance (I/M) status. In order to estimate emissions rates for MY2004 vehicles, the following input parameters were selected (see also "Sulfur Level, " above):

Emis. Std:	PZEV, SULEV II, ULEV II, LEV II, Tier 2 bins 1 through 11, Tier 1
Season:	Winter, Summer
Fuel:	RFG North, RFG South, Conventional
Sulfur:	Default national gasoline sulfur average (declining over time) for all gasoline vehicles except SULEV- and PZEV-certified vehicles; 30 ppm, lifetime average, for SULEV- and PZEV-certified gasoline vehicles; Default national diesel sulfur average (declining over time) for all diesel vehicles[1]
I/M:	None

MOBILE6 input files were coded to provide emission factors for a given vehicle class (LDV, LDT1-4, etc.), standard (Tier 2 bin 10, ULEV II, etc.), and pollutant (CO, HC, NO$_x$), in each of its assumed 25 years of life, beginning in 2004. Using VMT and survival rate weighting (described above and detailed in Table 8), this data was used to determine lifetime average emission rates for each vehicle class, emission standard, and pollutant. We judge that an OBD-only scenario best characterizes national average performance, so no I/M was selected.

Particulate emissions. In spite of the now-established concern about the adverse health effects of fine particulate matter emissions, few data are available to characterize the impacts of motor vehicle PM at the make and model level. Most data, as used for example to develop PM emission inventories, are highly aggregate. Established inventory models, such as EPA's PART5 model, generally characterize PM$_{10}$, while the greatest health concern is for much finer particles, typically in the sub-micron range. Characterization of PM, particularly ultrafine PM through particle count rather than mass-based measurements techniques, is an active area of research. At

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[1] The legislative phase-down of diesel sulfur levels occur on a different time schedule than gasoline sulfur levels; we model a linear phase-down of diesel sulfur from 300 ppm to 100 ppm between 2004 and 2006, with constant 15 ppm levels for years 2007 and beyond.

this point, PM emissions characterizations for motor vehicles remain highly uncertain and remain based on PM_{10} data.

MOBILE6 does not incorporate basic PM emission factors beyond those from the PART5 model (EPA 2003b). Delucchi (2001) and Wang (2003) estimate gasoline LDV emission rates of 0.022 and 0.012 g/mi, respectively, numbers consistent with the gasoline LDV emission rate of 0.021 g/mi used in previous years. Given the introduction of cleaner Tier 2 standards, an improvement in PM_{10} control is expected. However, health effects associated with finer particulates (in the sub-micron range) are likely to be underrepresented by a mass-based control approach. Therefore, we adopt an emission factor midway between the Delucchi and Wang estimates (i.e., 0.017 g/mi) for model year 2004 LDVs. Estimates for LDT1s and LDT2s are scaled up based on the ratios of modeled LDT1 and LDT2 emissions (0.015 g/mi each) to LDV emissions (0.012 g/mi) in Wang (2003), while emission factors of LDT3s and LDT4s are scaled up based upon the ratios of model year 2003 LDT2 to (1) LDT3 and (2) LDT4 PM standards, an approach consistent with our previous years' methodology (DeCicco and Kliesch 2002).

Although there is an eight-fold difference of the full-life PM emission standard between bins 2 and 10, it is believed that PM emissions are not a constraining pollutant for gasoline cars and smaller LDTs (Federal Register 2000). Furthermore, there is generally no deterioration in gasoline PM emissions (Glover 2003). Consequently, we maintain constant PM emission factors across emission standards for gasoline LDVs, LDT1s, and LDT2s. For LDT3s and LDT4s, we maintain constant PM emission factors up to Tier 2 bin 8 (where the full-life standard ranges from 0.01 to 0.02 g/mi), and only a 50 percent increase in emissions for LDT3s and LDT4s meeting bins 9 and 10 (where the standards are 0.06 and 0.08 g/mi, respectively). Appendix Table A1(d) identifies gasoline PM emission estimates for each vehicle class and emission standard.

Methodology for LEV I- and ULEV I-certified vehicles. After consultation with EPA, it was determined that MOBILE6 is not capable of providing emission factors of LEV I- and ULEV I-certified vehicles in an applicable format. Thus, for these certification levels, we adopt emission factors based on the Tier 2 bins with corresponding intermediate useful life emission standards (where available). For bins without intermediate useful life standards (i.e., bins 1-4), scaled ratios of full useful life emission standards are used. For example, as shown in Table 9, a LEV I-certified vehicle is modeled as having real world CO and HC emissions equivalent to bin 5 vehicles, and NO_x emissions equivalent to bin 9 vehicles. Particulate emissions for LEV I- and ULEV I-certified vehicles are determined as specified above in *Particulate Emissions*.

Because of the difference of the full-life durability requirement between LEV I and ULEV I (100,000 mile) and Tier 2 standards (120,000 mile), an adjustment is made to the LEV I and ULEV I emission factors to reflect greater deterioration for vehicles meeting those standards. For CO, HC, and NO_x, a linear extrapolation of the 50,000-mile and 100,000-mile standards is made to estimate a 120,000-mile emission factor (see Tables 9 and 10). These factors are then used to scale up real-world emissions estimates of the Tier 2 bins that correspond to the LEV I and ULEV I estimates. Appendix Tables A1 through A3 include resulting real-world emissions estimates of LEV I- and ULEV I-certified vehicles.

Methodology for LEV II-, ULEV II-, and SULEV II-certified vehicles. MOBILE6 does not incorporate explicit modeling of LEV II-certified vehicles. Documentation of the model, however, (with confirmation by staff at EPA's Air Quality and Modeling Center), specifies the process by which an external input file (T2CERT.d) can be modified to model the effects of California's LEV II program (EPA 2002; Landman 2003). Because MOBILE6 utilizes 50,000-mile exhaust emission standards, modeling LEV II and ULEV II vehicles can be achieved by simply incorporating the appropriate emission standards into the external input file. SULEV II vehicles, however, do not have a 50,000-mile standard. In order to incorporate SULEV II vehicles into the model, ratios between the 50,000-mile and 120,000-mile standards for LEV II and ULEV II vehicles are compared.

As shown in Table 7 below, the ratios between 50,000-mile and 120,000-mile standards for CO and NO_x are the same in LEV II and ULEV II vehicles. Those ratios are applied to estimate a 50,000-mile level for SULEV II vehicles. For NMOG, the ratio of ULEV II (1.38) is selected to use as a basis for estimating the 50,000-mile SULEV II level, because of its closer proximity to SULEV II vehicle characteristics.

Methodology for PZEV-certified vehicles. Methodologically, the handling of partial-ZEV (PZEV)-certified vehicles is consistent with previous editions of *ACEEE's Green Book*®. Following the emissions requirements specified by the California Air Resources Board, these models are evaluated as SULEV II-certified vehicles with 150,000-mile performance and zero evaporative emissions (CARB 2002). In order to account for the 150,000-mile durability of these vehicles, the estimated 50,000-to-120,000 mile SULEV II ratios (specified in Table 7) are extrapolated to assume 150,000-mile compliance at the SULEV II emission standards. Resulting estimated 50,000-mile standards for PZEV vehicles are 0.645 g/mi, 0.006 g/mi, and 0.011 g/mi for CO, HC, and NO_x, respectively. Real-world in-use estimates are specified in Appendix Tables A1-A3.

Because MOBILE6 includes emissions that occur independent of roadway type (which includes evaporative emissions), PZEV-certified models are post-corrected by subtracting the evaporative portion of gasoline SULEV vehicles used in model year 2003 and earlier methodologies, to reflect their "zero-evap" status.

Diesel emissions. Real-world data on diesel tailpipe emissions are even more limited than for gasoline vehicles. Although profiling of diesel vehicles is being investigated by EPA, in-use data on emissions from Tier 1 and newer vehicles is extremely limited (EPA 2001c). In lieu of more current information, EPA uses Tier 0 emission factors, scaled down by the ratio of the Tier 2-to-Tier 0 standard, in MOBILE6 calculations (EPA 2001b; 2001c). However, the large differential between Tier 0 and Tier 2 standards yields a modeling of diesel vehicles with lower emissions (including NO_x) than gasoline vehicles having the same certification. Barring significant advances in diesel aftertreatment, the outcome with respect to NO_x is incorrect, and raises questions about this methodological approach in general.

Given the lack of data, we use zero-mile levels and deterioration rates for CO, HC, and NO_x, as specified in EPA (2001b), in conjunction with MOBILE6-specified annual VMT levels, to generate VMT- and survivability-weighted lifetime average emissions of diesel cars and trucks. Because these rates do not include off-cycle (non-FTP) driving patterns, they are then broken into on- and off-cycle apportionments using the 72% on-cycle, 28% off-cycle breakdown specified in the SFTP Final Rule (Federal Register 1996). For example, since the lifetime average LDV on-cycle NO_x estimate of 1.14 g/mi comprises 72% of combined on- and off-cycle emissions, a resulting 0.45 g/mi accounts for the off-cycle portion of total emissions. These resulting emission factors are roughly consistent with previous *Green Book* estimates, and are assumed to depict the emissions of a vehicle meeting the certification level of Tier 2 bin 10 for LDVs, LDT1s, and LDT2s; and Tier 2 bin 11 for LDT3s and LDT4s.

Modeled real-world CO, HC, and NO_x emissions of Tier 2 bin 10 and Tier 2 bin 11 gasoline vehicles are used to generate ratios of gasoline-to-diesel levels for each pollutant and vehicle class. Using the bin/vehicle class division specified above, these ratios are then applied to gasoline emission estimates at the remaining certifications to estimate CO, HC, and NO_x emission factors of diesels certified to other levels. This process is largely academic at this point in time, however, as most diesel vehicles are certified to minimally-stringent standards. The majority of MY2004 diesel vehicles were certified to Tier 2 bin 10, with remaining models meeting either Tier 2 bin 9 or Tier 1.

Modeled real-world CO, HC, and NO_x emissions of Tier 1-certified diesel LDTs are determined through a scaling process using gasoline Tier 1 emissions estimates, gasoline Tier 2 bin 11 estimates, and diesel Tier 2 bin 11 estimates. The ratios of real-world gasoline Tier 1 to bin 11 emissions for LDT3s, LDT4s, and Class 2b Trucks were multiplied by the diesel bin 11 LDT3, LDT4, and Class 2b Truck values, respectively, to yield diesel Tier 1 estimates for those vehicle classes. Because the Tier 1 certification option for model year 2004 applies only to heavier trucks, emissions estimates were not made for LDVs through LDT2s.

In a manner consistent with our previous years' methodologies, PM emissions for diesel LDVs through LDT2s are estimated by multiplying the gasoline lifetime average estimates by the ratio of diesel vehicle PM exhaust emissions to gasoline vehicle exhaust emissions (0.10 g/mi / 0.012 g/mi) for those vehicle classes specified by Wang (2003). LDT3s and LDT4s are scaled up based on the ratio of model year 2003 LDT2 to LDT3 and LDT4 PM standards (0.08, 0.10, and 0.12 g/mi, respectively). This comprises the bin 10 diesel PM emission factors for each vehicle class. To scale between bins 5 and bin 11, each vehicle class' bin 10 emission factor is scaled based on the Tier 2 PM emission standard (which ranges from 0.01 g/mi to 0.12 g/mi). Resulting diesel emissions estimates are shown in Appendix Tables A3(a)-A3(d).

Compressed natural gas vehicles. A set of emission factors was also developed for compressed natural gas vehicles. Bi-fuel vehicles are not specifically covered in *ACEEE's Green Book®*. Automakers' dedicated CNG vehicles meet a range of emission standards this model year, from Tier 2 bin 10 to PZEV. Emission factors of "near-term" vehicles specified in Argonne National Laboratory's GREET1.6 model (Wang 2003) were selected as the basis for a CNG passenger car meeting the LEV I-ULEV certification. As in previous years, emissions estimates for vehicles certified to cleaner standards are scaled down based upon each pollutant's ratio to the LEV I-ULEV emission standard. Similarly, estimates for CNG LDTs are scaled up based on the ratio of LEV I-ULEV LDV-to-LDT emission standards. (See Appendix Tables A2(a)-A2(d) for more information.) The resulting estimates imply CNG vehicle in-use emissions, particularly of NO_x and HC, that are lower than those of gasoline vehicles certified to an identical standard. This result is consistent with third-party tests of CNG vehicles such as those reported by Weaver and Chan (1997).

Methodology for Class 2b Trucks

Vehicles between 8,500 and 10,000 lb. GVW (also known as MDPVs – Medium Duty Passenger Vehicles – or Class 2b trucks) are not subject to the same emissions and fuel economy regulations, or data reporting and labeling regulations, as LDVs and LDTs. An increasing number of these vehicles, however, are variants of LDTs and are sold as personal vehicles. Inclusion of these vehicles in our ratings required the development of a procedure for estimating the vehicles' lifetime average real-world emissions in a manner consistent with vehicles subject to light-duty regulations.

Although MOBILE6 is configured to model the emissions of Class 2b trucks, results from the model are inconsistent with its analysis of trucks in the next-lowest weight class, LDT4. Specifically, MOBILE6 estimates 2b trucks as having CO and HC emissions lower than LDT4s, while having NO_x emissions significantly higher than LDT4s. After consultation with members of EPA and a MOBILE modeling expert (Byun 2003), it was decided to continue the use of our existing methodology for evaluation of Class 2b trucks, as detailed below.

Since Class 2b trucks are exempt from Corporate Average Fuel Economy (CAFE) standards, EPA does not collect fuel economy data. In the past, we have mailed letters to manufacturers of these vehicles, requesting fuel economy data and related specifications for their trucks. No automakers provided us with such data. Therefore, we developed a procedure for estimating Class 2b truck fuel economy and emissions by scaling from an LDT model of which the 2b model is a variant. For example, if a version of a large, 2WD pickup truck is classified as an LDT4, fuel economy and emissions certification information data for it are available in an EPA database. A 4WD variant (with the same engine), however, may weigh more than 8,500 lb. GVW, and thus is not listed in the EPA database. Therefore, we estimate the 4WD version's fuel economy and emissions by scaling the estimates for a 2WD (LDT4) version that contains the same engine.

Fuel economy estimation. To estimate Class 2b truck fuel economy, we scale from the corresponding vehicle's LDT fuel economy as described below. This scaling is done using mass sensitivity coefficients derived from the An and Ross (1993) fuel economy model. We use a coefficient of -0.27 for city fuel economy and -0.23 for highway. Given the small mass differences, a linear approximation is used; in the city cycle case, for example:

$$MPG_2 = MPG_1 [1 - (0.27) (m_2-m_1)/m_1]$$

where "m" designates mass (vehicle curb weight), MPG is fuel economy, and subscripts refer to the base LDT for which fuel economy is known (1) and the Class 2b variant for which fuel economy needs to be estimated (2). These coefficients assume that other key vehicle parameters are constant; in particular, engine displacement is constant because we address only Class 2b trucks matched by engine and transmission type to a given LDT. Parameters that would also affect fuel economy, but for which we did not adjust, include gear ratios, the n/v (rpm per mph) ratio, and driveline friction, among others. For example, higher n/v and higher driveline friction in a Class 2b variant would push its actual fuel economy lower than what we estimate; however, these data were not readily available. Ideally we would like to have Class 2b truck fuel economy data from the standard LDV/LDT test cycles.

Emissions estimation. To estimate tailpipe emissions, we assumed that Class 2b truck emissions are not much higher than those of corresponding LDT versions. This assumption is based on discussions with EPA staff and other experts, who confirmed that emissions control technology is similar for Class 2b and LDT versions of most light trucks, including, most notably, the use of 3-way catalysts for gasoline vehicles. We adopt, therefore, a method of scaling up emissions factors from LDT4 emission factors. A review of Class 2b truck specifications yielded an average Class 2b inertial test weight (ITW) to be approximately 300 lb. heavier than its LDT4 counterpart. Thus, we use a load-based scaling in which we multiply LDT4 emission factors by the ratio of average Class 2b ITW to average LDT4 ITW. These load-scaling factors are shown in Appendix Table A1, and the resulting emission factors are shown in Appendix Tables A1(a)-(d) for gasoline vehicles, A2(a)-(d) for CNG vehicles, and A3(a)-(d) for diesels.

Evaporative Emissions from Vehicles

Hydrocarbon vapors leak from fuel tanks, lines, and other fuel system components of a vehicle. These evaporative emissions are regulated by EPA and CARB by means of a test wherein stationary vehicles are placed in controlled chambers and subjected to a range of temperatures for a set amount of time. The mass of fuel evaporated is measured, giving results in grams of HC per test.

MOBILE6 is used to estimate evaporative emissions for vehicles meeting most emission certifications; where additional calculations are necessary, we use evaporative emissions factors in grams/gallon (g/gal), derived from Delucchi (1997b), rather than grams/test levels for consistency with other aspects of our methodology. Following Delucchi (1997b), we assume negligible evaporative emissions for diesel and CNG vehicles, as well as for gasoline vehicles meeting the PZEV zero-evaporative emissions standard. Our estimation of evaporative hydrocarbon emissions in gasoline SULEV vehicles is determined by multiplying our estimate of gasoline ULEV evaporative emissions, as noted in Delucchi (1997b), by the ratio of LEV to LEV II 3-day diurnal tests (0.5/2.0 g/test). Details of our estimates for LDV evaporative emissions are provided in Appendix Table B1.

As mentioned above, MOBILE6 calculates vehicle evaporative emissions, but aggregates them with other emissions that occur independent of roadway type. In order to properly evaluate the "zero-evap" status of PZEV-certified models within our computational framework, PZEV-certified models are post-corrected by subtracting the evaporative portion of SULEV gasoline vehicle emissions, as defined above.

Unregulated In-Use Vehicle Emissions

Tailpipe emissions of SO_2, N_2O, CH_4, and CO_2 are not regulated by vehicle, although SO_2 emissions are linked to restrictions on fuel sulfur content. These emissions do not depend on a vehicle's certification level but are related to the amount of fuel consumed depending on fuel type. Delucchi (1997b) estimates these emissions on a grams-per-mile basis, which we convert to a grams-per-gallon value using his assumed average fuel economy (MPG). Since Delucchi does not estimate light-duty diesel emissions, but the fuel is the same for all vehicles, we use the heavy-duty diesel vehicle grams per mile estimates and convert them to grams per gallon values. Of these emissions, SO_2 makes a significant contribution to health damages; N_2O, CH_4, and CO_2 are greenhouse gases. Estimation details are given in Appendix Table B1.

FUEL CYCLE EMISSIONS

Pollution occurs throughout the fuel production cycle, from the well head to the fuel pump for gasoline or from the coal mine to the wall plug for electricity, for example. HC emissions associated with refueling are included as part of these fuel cycle emissions, but those that occur once fuel is in a vehicle are included under "Evaporative Emissions," above. Delucchi (1997b) models full fuel cycle emissions of CO, HC, NO_x, PM_{10}, SO_2, CH_4, N_2O and CO_2 for gasoline, diesel, CNG, electricity, and other alternative fuels. His results are expressed in grams per million British thermal units (grams per 10^6 Btu), and those relevant to our analysis are detailed in Appendix Table B2. We then computed grams per mile estimates from each vehicle's estimated in-use fuel economy, which is estimated as described below. The difference between in-use and upstream emissions for gasoline-, diesel-, and CNG-powered vehicles is illustrated in Appendix Tables B1 and B2.

Fuel Economy and Shortfall

Though not perfect, the certainty level for fuel economy is much better than that for vehicle emissions. Simulated driving tests overestimate fuel economy—MPG is higher on the test cycles than in real-world driving—but the bias is fairly well known. Since 1984, EPA has adjusted city MPG downward by 10% and highway MPG downward by 22% for labeling purposes. These adjustments imply a "shortfall" of roughly 15% compared to the composite 55% city, 45% highway MPG used for CAFE compliance purposes. Changing traffic conditions appear to have increased the shortfall, and available evidence suggests that it varies with vehicle class, being worse for many light trucks (Mintz, Vyas, and Conley 1993). Therefore we adjusted the composite (CAFE-compliance, rather than label) fuel economy downward by 18.7% for cars and 20% for light trucks. The error remaining after such adjustments is probably less than 10%. This modest uncertainty in fuel consumption rates is a marked contrast to the situation for vehicle emissions rates, where residual errors are quite large and only crudely quantifiable (e.g., within a factor of 2 or more).

All emissions associated with charging an electric vehicle (EV) fall under the fuel cycle category. We use power consumption (kilowatt-hours per mile) data supplied directly by automakers for their electric vehicles; we list these data as an efficiency rating (miles per kilowatt-hour) in our tables. Electricity losses during recharging are included in the EV efficiency rating, so the fuel cycle emissions factors reflect electricity generation and distribution losses, but not the losses associated with end-use charging equipment. We use DOE (2001) estimates for a national average power generation mix as detailed in Appendix Table B3. Our valuation assumptions for health effects treat power plant emissions differently than vehicle emissions; as discussed below, this issue (related to differences in exposed population) is more important than the geographic differences in electricity generation mix.

MANUFACTURING EMISSIONS

Energy is consumed in the assembly of vehicles and to an even greater extent is embodied in the production of raw materials. We characterize the associated impacts by averaging aggregate automobile manufacturing sector statistics over an assumed 100,000 mile vehicle lifetime.

For GHGs, we start with the DeLuchi (1991) estimate of CO_2-equivalent emissions associated with vehicle manufacturing as 55.9 g/mi for a 2187 lb. car, implying an mass-based emissions factor of 0.056 g/mi per kg of vehicle.

For NO_x, SO_2, and PM_{10}, we estimate the emissions associated with energy use for materials production and manufacturing, also assuming proportionality to mass. This procedure involves three principal inputs:

1. Mass fractions of major materials (metals, plastics, rubber, glass, etc.) in an average vehicle;

2. Energy use by fuel (electricity, coal, oil, or natural gas) for producing each material (e.g., joules per kilogram of material); and

3. Manufacturing and electric power generation emissions factors by pollutant for each fuel (e.g., grams of NO_x, SO_2, and PM_{10} per joule of fuel consumption).

These calculations are detailed in Appendix Tables C1-C3. The resulting emission factors in grams per mile per kilogram of vehicle mass are shown in Table 2.

In order to account for the environmental impacts beyond those associated with manufacturing-phase energy consumption, we include the impacts of toxic pollutant releases and transfers as determined from Toxic Releases Inventory (TRI) data. EPA provides toxic transfer and release information associated with the motor vehicle portion of the Transportation Equipment sector, denoted as Standard Industrial Classification (SIC) 371. Releases associated with SIC 371 (which includes SICs 3711, 3713, 3714, 3715, and 3716) are found in Tables 14-1 and 14-3 of EPA (1998). Additionally, in order to account for facilities that reported multiple codes on their TRI forms, we also included the relevant releases and transfers from Table 14-2.

Our determination of a summary estimate of TRI releases and transfers (on a per vehicle basis) is consistent with the methodology utilized by Keoleian et al. (1997), as applied in DeCicco and Thomas (1999a). We calculate summary estimates of 6.4 lb. of TRI releases and

13.9 lb. of TRI transfers per vehicle using 1996 TRI data and 1996 U.S. production figures of 11.7 million vehicles (Automotive News 1999). We assume that the damage associated with transfers is one order of magnitude less than that of releases. The total toxic release-equivalent is then 6.4 + 1.39 = 7.8 lb. (or 3.5 kg) per vehicle. Using the 1996 average light vehicle curb weight of 1460 kg implies 2.42 g/kg (i.e., 2.42 grams of toxic emissions per kilogram of vehicle), representing embodied TRI impacts. Updating to 1996 from our earlier use of 1993 TRI data proved to have minimal impact (1% or less) on lowering an average vehicle's EDX.

Electric Vehicle and Hybrid-Electric Vehicle Battery Replacement

Total vehicle weight is used in the calculation of embodied NO_x, SO_x, PM_{10}, toxic, and GHG emissions. Similarly, we choose to evaluate the total life cycle mass of an electric vehicle by including the mass of batteries used over its lifetime. To perform this calculation, information about each EV's battery type and mass must be acquired from its respective automaker. Since automakers' claims regarding battery lifetimes are highly variable, it was decided to use battery lifetime approximations based on the battery type. Consultation with EV battery researchers in both industry and government during the MY2000 methodological update led us to develop lifetime approximations of 2.5-year, 5-year, and 6-year lifetimes for lead-acid, lithium-ion, and nickel-metal-hydride EV batteries respectively (although all EVs produced in quantity as MY2002 vehicles contained either NiMH or PbA batteries). A 10-year lifetime was assumed for all vehicles.

The following formula is used to calculate the adjusted vehicle mass, m_v' :

$$m_v' = (m_v - m_b) + (\frac{l_v}{l_b}) * m_b$$

where m_v' = adjusted vehicle mass

m_v = base vehicle mass (curb weight, including original battery)

m_b = battery mass

l_v = vehicle lifetime (years)

l_b = battery lifetime (years)

The model year 2003 methodology included emissions embodied in replacement supplemental-power batteries of hybrid-electric vehicles, using a mass-based estimation of environmental impacts as noted above. Warranted mileage of the battery was used as a proxy for battery lifetime. The overall incorporation of battery replacement in the evaluation of hybrid-electric vehicles yielded a very small impact on EDX and Green Score: the long battery lifetime and low mass (compared to our similar methodological approach with battery-electric EV batteries) served to reduce the impact of this methodological change to an EDX increase of less than one percent.

Based on comments we received that disputed the correlation between a battery's warranted mileage and its actual mileage, this methodological adjustment for hybrid-electric vehicles was removed for model year 2004. Again, doing so yielded a very small change in the resulting vehicle score.

IMPACT VALUATION AND RESULTS

For characterizing the environmental damage of various emissions over the vehicle life cycle, we adopt an approach based on environmental economics. Our environmental damage index weights the relative impacts of the pollutants using factors derived from damage cost estimates. It also involves a non-economic judgment that assigns a monetary value to greenhouse gases relative to the economically derived values for conventionally regulated pollutants.

In economic terms, most environmental impacts are considered externalities, that is, effects on others that are not accounted for in market transactions by the parties causing the effects. Delucchi (1997b) places the human health externalities of air pollution from U.S. motor vehicle use at $24–450 billion per year (1991$). These estimates correspond to a per-vehicle external cost of $140–2,500 per year. The large range reflects the uncertainty inherent in such estimates; nevertheless, the evidence is quite strong that the costs are non-zero.

ENVIRONMENTAL DAMAGE COSTS

Among the common approaches for estimating environmental externalities are use of control costs and use of damage costs. Control costs are based on observations of the costs incurred to reduce pollution such as the cost of clean-up devices. Damage costs are based on observations of the harm caused by pollution, derived, for example, from epidemiological studies. We use damage costs, which avoid incorrect valuation due to: (1) market, regulatory, and implementation imperfections that lead to control costs being different than damage costs; and (2) the fact that existing pollution controls already internalize some of the costs. Examples of such internalization are the higher cost of a car due to its emissions control system and the higher cost of gasoline due to reformulation requirements.

The harm caused by air pollution depends on where it is emitted relative to exposed populations and other subjects of concern. Transported pollutants are subject to dilution and transformation. The impact of, say, one gram of PM emitted from a vehicle tailpipe differs substantially from the impact of one gram of PM emitted from a power plant. Thus, a single damage cost value should not be used for a given pollutant independently of where it is emitted. Delucchi and McCubbin (1996) examined this issue in some depth for the major pollutants associated with motor vehicles and their supporting infrastructures (including manufacturing plants, petroleum refineries, electric utilities, etc.). They simulated the fraction of a pollutant, emitted from a given source, which would reach exposed subjects in various locations. Their simulation results were normalized relative to exposures to light-duty vehicle PM emissions, yielding what might be called damage cost reduction factors. Reviewing the wide range of resulting factors, we selected a factor of ten for reducing the damage cost of pollutants from electric utilities relative to those from vehicles. We selected a reduction factor of five for factories and refineries, which entail relatively higher worker and community exposures.

For base damage costs—those representing the impacts of pollutants directly emitted from motor vehicles—we adopted the geometric means of the low and high health cost estimates of Delucchi (1997a, Table 1-A1). The resulting estimates for major pollutants by location are shown in Table 3. These estimates place a relatively high value on reduction of fine PM and its precursors (particularly SO_2 and NO_x). In contrast, earlier estimates (e.g., as in the review by Wang and Santini 1995) emphasized reduction of ozone and its precursors, resulting in a relatively high value for avoided HC emissions. Established vehicle regulations place a high premium on ozone reduction, with a strong emphasis on reducing HC. California's smog index (CARB 1996) matches the type of valuation implied, for example, by Wang and Santini (1995) estimates, in which the damage cost ($/kg) of HC is about 50% of that of NO_x. By contrast, the damage cost of HC is only 8% of that of NO_x for the Delucchi (1997a) estimates that we adopt here. Thus, our valuations imply relatively small differences among California LEV I standards, which are strongly oriented to HC reduction and cut NO_x by only a factor of two from the Federal Tier 1 level. Relative to the Tier 1 standard, our valuations reflect a significantly greater benefit for Tier 2 and LEV II standards, which, depending on bin (or the specific LEV II standard), can cut nominal NO_x emissions by a factor of eight or more.

Since the average U.S. electricity generation mix includes a significant share (23%) of nuclear power, it is necessary to include the environmental damage associated with the nuclear fuel cycle. Its environmental impacts fall largely outside of the criteria air pollutant and GHG impacts on which we base our damage cost estimates for fossil fuels and their products. External costs of nuclear power have been extensively investigated for electric sector studies. Population exposures to radiation occur during uranium extraction and processing to produce nuclear fuel, during normal reactor functioning, and during radioactive waste disposal and plant decommissioning. Many of these latter impacts are highly uncertain because these end-phases of the nuclear fuel cycle are far from fully addressed. The most problematic cost is that associated with accidents, which can be disastrous, but are rare and unpredictable and so are very poorly amenable to statistical characterization.

Ottinger (1991, 34) provides summary external cost estimates of 0.11¢/kWh for routine operations, 0.50¢/kWh for decommissioning, and 2.3¢/kWh for accidents. The accident portion is based largely on allocating the damage estimates associated with the Chernobyl disaster over the operating history base of nuclear power. (Impacts of the worst U.S. accident, at Three Mile Island, are nearly negligible in comparison to Chernobyl.) Given the relatively safe history of U.S. nuclear operations, and the high uncertainty associated with accident estimates, we use only the two non-accident costs, implying an external cost of 0.61¢/kWh for nuclear power as part of the U.S. average electricity generation mix. As shown in Appendix Table B3, prorating this estimate by the 23.4% share of nuclear power in the mix adds 0.14¢/kWh (about 20%) to the overall external cost of electricity, which we estimate at 0.71¢/kWh. This value is used to calculate the environmental damage from electric vehicle use and electricity used in vehicle manufacturing.

Damage cost estimates for toxics are not readily available. TRI includes an extensive list of substances, many of which are hydrocarbons, but their control concerns are as much for toxicity as for ozone formation, and some are metallic compounds, including carcinogens, mutagens, etc. We treat these TRI-based emissions as if they were PM_{10} released at manufacturing sites. For our EDX calculations, we add the toxics estimate to the PM emissions embodied in manufacturing energy use. Multiplying the resulting PM emission factor (2.83 g/kg) by the damages cost factor for manufacturing PM emissions ($7.22/kg) implies a cost of $20.43/tonne of vehicle.

It is extremely difficult, if not impossible, to estimate meaningful damage costs for GHG emissions. Published estimates tend to be relatively small in magnitude. For example, based on a literature review of GHG damage estimates, Delucchi places aggregate global warming externalities from U.S. motor vehicle use at over a factor of 30 lower than air pollution health externalities (Delucchi 1997a, Table 1-9A). A number of analysts have examined GHG control (mitigation) costs and the span is quite wide. For example, costs of carbon sequestration through reforestation range from $2/T_C$[1] for plantations in Central America to $200/T_C$ for plantations in North America (Ottinger 1991, 165-185). Global warming, like other issues of sustainability, transcends traditional analyses. Concern is well established in the scientific community (IPCC 1995). The Kyoto Protocol adopted in December 1997 committed developed nations to net reductions of their GHG emissions over the next 10 to 15 years.

In light of these considerations, we treat GHG emissions as being equally important as traditionally regulated air pollutants in determining the rating of an average vehicle. In our original edition, a quasi-damage cost for CO_2-equivalent GHG emissions was calculated so that, for an average vehicle, one-half of the EDX would be GHG-related and the other half would be equal to the sum of the health damage costs from other pollutants (the total estimated health effects of PM, NO_x, VOC, etc.). This year, we retained the same quasi-damage cost ($63/T_C$, or $0.0171/kg on a CO_2-equivalent mass basis), effectively increasing our GHG weighting slightly to reflect the progress being made on tailpipe pollutant reductions and the lack of improvements being made in vehicle greenhouse gas reductions.

SUMMARY OF LIFE CYCLE ESTIMATES

We compiled a database of all new light-duty vehicles on the U.S. market in 2004 and carried out the rating analysis for each configuration of every make and model (1,699 in all). Figure 2 shows the resulting EDX distribution: (a) for the overall light-duty fleet and (b) separately for cars and light trucks. These results are not sales-weighted and so represent the "menu" of vehicles offered to the market, as opposed to market outcome. The 2004 EDX results range from 0.99¢/mi (a PZEV-certified compressed natural gas compact car) to 4.96¢/mi (a diesel-powered, 10-cylinder, 4-wheel drive sport utility vehicle). The median is 2.35¢/mi and one-half of the models fall between 2.10 and 2.72¢/mi.

Tables 4 and 5 detail the EDX calculations for an average model year 2004 car and light truck, respectively. The first three parts of the table itemize health-related criteria emissions impacts for: (a) direct vehicle emissions; (b) fuel cycle emissions; and (c) emissions embodied in materials and vehicle assembly. Lifetime average (g/mi) emissions rates are multiplied by damage costs from Table 3 to obtain life cycle cost estimates in cents per mile. For the average

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[1] "T_C" refers to metric tons expressed on a carbon-mass basis.

car, the three criteria emissions components are, rounded, 0.50¢/mi (53%) at the vehicle, 0.24¢/mi (25%) from the fuel cycle, and 0.21¢/mi (22%) embodied, summing to 0.96¢/mi (100% of life cycle criteria emissions impact as calculated here). The criteria emissions components for the average 2004 light truck are nearly equally distributed (55% at the vehicle, 25% from the fuel cycle, and 20% embodied), albeit with a sum total of 1.37¢/mi—43% higher than the criteria emissions total of the average 2004 car.

Greenhouse gas emissions calculations are shown in Tables 4(d) and 5(d). Emissions from each source, drawn from parts (a)–(c) of the table, are summed and then multiplied by the global warming potential (GWP) that represents the radiative forcing of each GHG species compared to that of CO_2 (Delucchi 1997b). The total lifetime average CO_2-equivalent emission rate (e.g., 668 g/mi for the average car) is then multiplied by the quasi-damage cost chosen for GHG emissions. In earlier editions of *ACEEE's Green Book*®, the GHG impact and health-related (criteria emissions) impact were the same by definition, under our assumption that GHG emissions were as important as criteria emissions in determining the average vehicle's EDX. The past few years, however, we have maintained the MY1999 damage cost factor for GHG emissions so that its weighting now accounts for about 54% of the EDX of both the average car and light truck. With this assumed GHG damage cost factor, GHG impacts total 1.14¢/mi for the average car and 1.56¢/mi for the average light truck. The GHG total breaks down as approximately 69% at the vehicle, 19% from the fuel cycle, and 12% embodied for the average car and nearly the same (68%, 19%, 13%, respectively) for the average light truck. The criteria- and GHG-related calculations are summarized in Tables 4(e) and 5(e), with resulting total EDXs of 2.10¢/mi and 2.93¢/mi, respectively, corresponding to Green Scores of 32 and 21.

Figure 2 illustrates how U.S. vehicles fall into two major classes: passenger cars (coupes, sedans, and station wagons) and light trucks (pickups, minivans, and sport utilities). The distributions are bimodal due to both the different regulatory treatment of car and light truck fuel economy, and emission certification distributions that occur under the early years of the Tier 2 regulatory scheme. The EDX for the median passenger car is 2.18¢/mi, while that for the median light-duty truck is 2.80¢/mi, about 28% higher.

Most light trucks fall into the LDT2 category. This model year, the majority of LDT2 vehicle configurations are certified to Tier 2 bin 9, the same standard to which the majority of passenger cars are certified. Nonetheless, real-world estimates indicate greater in-use emissions from a LDT2. Furthermore, the differences in emissions are compounded by differences in fuel economy standards, which are 27.5 MPG for cars and 20.7 MPG for light trucks in 2004 (implying a 33% higher fuel consumption rate for the trucks). The mass disparity between the car and light truck classes serves to further reinforce the bimodality. Since light trucks now account for 50% of vehicle sales, the majority of environmental degradation caused by MY2004 vehicles over their 12+ year lifetime will come from light trucks.

PUBLIC PRESENTATION OF RESULTS

Representing a vehicle's environmental damage as a lifetime average external cost per mile, the EDX is an abstraction that may be difficult for many consumers to appreciate. Therefore, to facilitate communication and make it easier to compare vehicles, we derived from the EDX two indicators to convey rankings in *ACEEE's Green Book*®. One is a Green Score on a higher-is-better scale of 0 to 100. The other is a set of class ranking symbols that compare vehicles within a given size class.

The Green Score allows comparisons both within and across classes. It is not tied to a particular model year, so it can accommodate updates to the methodology while maintaining a consistent scale for consumers. It also leaves room to reflect future improvements in vehicle environmental performance. To map the EDX from a [0,∞] range inversely to the Green Score on a [0,100] range, we use a gamma function to spread out the scores for future "green" vehicles at the expense of less differentiation among current vehicles. Presently, in fact, the variability in EDX within most vehicle classes is relatively small. The mapping, shown in Figure 3, is:

$$\text{Green Score} = a \cdot \frac{e^{-\text{EDX}/c}}{(1 + \text{EDX} / c)^{b}}$$

with a = 100, b = 3 and c = 6.59¢/mi. A perfect score of 100 is unattainable since it would require an EDX of 0. Using the parameters shown, model year 2004 Green Scores range from 9 to 57, with an overall average of 27.

When car shopping, many consumers target a given vehicle class and are unlikely, for example, to consider a subcompact when looking for a minivan. To facilitate comparisons within classes, we developed the symbolic, five-tier class ranking scheme shown in Table 6. In assigning class rankings, we considered the number of vehicles in each class and natural breaks in the distribution rather than rigidly applying the cutpoints listed in the table. An additional constraint was that no vehicles that scored worse than the model year average (a Green Score of 27, corresponding to an EDX of 2.44¢/mi) could obtain the Superior ranking. Details of the EDX distributions and exact cutpoints used for each class are provided in Appendix E.

AREAS FOR FUTURE WORK

This methodology provides a flexible framework that can be refined and updated as new data become available. The parameters and assumptions described in this document reflect updates made since the original 1998 edition. (Appendix F describes the updates made for this current edition.) Several areas for improvement are highlighted below and the author looks forward to receiving comments regarding other methodological issues to address.

IN-USE EMISSIONS

Characterization of in-use vehicle emissions is an ongoing area of effort. A multiyear time lag occurs from when a new vintage of vehicles is sold until in-use experience accumulates, data are gathered, and analysis is reported. Thus, it is necessary to rely on past data and modeling projections. This year's methodology draws heavily on EPA's MOBILE6 vehicle emissions model. In the coming years, we will continue to refine the use of computer models in our methodological approach, as well as to incorporate new models (such as EPA's MOVES model) when they become available.

Vehicles certified to the California and Federal standards phased into the fleet since 1994 appear to have substantially better in-use performance than had been observed historically. The phase-in of the Supplemental Federal Test Procedure between 2001 and 2004, requiring better control of off-cycle emissions, is likely to yield even greater improvements. ACEEE will continue to review data and adjust the in-use emissions parameters for each new model year. A greater commitment by government and industry to report extensive and realistic in-use emissions data will be most valuable for improving both government emissions analysis and our rating methodology.

MATERIALS USE AND MANUFACTURING IMPACTS

As noted earlier in this report, materials production and manufacturing (as well as end-of-life) phases of the vehicle life cycle are poorly represented in the current methodology. The reason for this is a lack of data linked to makes and models. Room exists for further consultation with LCA experts, the industry, Federal and state agencies involved in industrial pollution issues, and other experts. Nevertheless, data limitations will remain a constraint unless an industry-wide system for gathering and reporting the relevant data is developed. Given sufficient research resources and opportunities for collaboration with academic, industry, and environmental experts, we hope to explore these issues further. If interest exists, we are open to holding a workshop or series of meetings that can lead to the development of improved characterizations of pre- and post-use phase impacts, including ways to rate material production, supply chain, assembly, recyclability and recycled content, and end-of-life management.

CONSUMER RESPONSE STUDIES

It is important that the understandability and usefulness of green rating information, and how it is presented, be investigated. It will be useful to solicit views and recommendations from market researchers and behavioral scientists who have experience in environmental ("green") purchasing generally, the automotive market, or both, as well as to perform market research on *ACEEE's Green Book*® itself. ACEEE will pursue such studies and will also coordinate with others in government, industry, and other organizations who are also interested in exploring consumer acceptance of new vehicle technologies and related topics regarding the potential for "green" buying in the automotive sector.

CONCLUSION

Developing and refining *ACEEE's Green Book*® involves exploring many issues related to the life cycle environmental impacts of vehicles and how they can be communicated to consumers. Our ratings can help foster a market for vehicle designs and technologies with reduced environmental burdens, which will be crucial for progress toward an environmentally sustainable transportation system. We welcome suggestions for improving *ACEEE's Green*

Book®*: The Environmental Guide to Cars and Trucks* in terms of both methodology and presentation.

Table 1. Life Cycle Assessment Matrix for Estimating Motor Vehicle Green Ratings

	Phase of Product Life Cycle				
Environmental Concern	Materials Production	Product Manufacture	Product Distribution	Product Use	End of Life
Air Pollution	C	C		B	
Energy Consumption	C	C		A	
Greenhouse Gas Emissions	C	C		A	
Land Contamination					
Noise					
Water Pollution					
Worker/Community Health					
Other Ecosystem Damage					
Other Resource Consumption					

Status in the *ACEEE's Green Book*® methodology (blank cells indicate items not included):
A—Included explicitly, with good data quality and relatively high accuracy for discriminating among vehicles.
B—Included explicitly, but with lower level of data quality and relatively high uncertainties.
C—Included only indirectly, with very aggregate or uncertain data.

Table 2. Evaluation of Impacts from Vehicle Manufacturing (Embodied Emissions)

Pollutant	Grams of Pollutant per kg of Vehicle [a]	Damage Cost [b] ($/kg Pollutant)	Cost $/tonne of Vehicle
NO_X	19.8	0.90	18
SO_2	24.3	4.25	103
PM_{10}	2.83	7.22	20
Subtotal			141
CO_2 [c]	5600	0.0175	98
TOTAL			**239**
Cents per pound of vehicle			10.9
Cents per pound of vehicle per mile (assuming 100,000 mile lifetime)			1.1×10^{-4}

Notes:

a. Derived as described in text, with details given in Appendix Tables C1-C3.
b. See discussion and Table 3, below.
c. Derived from DeLuchi (1991), Table 9, estimate of 55.9 g/mi for a 2,187 lb. car.

Table 3. Damage Cost Estimates for Principal Air Pollutants

POLLUTANT	MARGINAL COST BY LOCATION OF EMISSIONS (1991$/kg)		
	Motor Vehicles [a]	Refineries and Factories [b]	Electric Power Plants [c]
CO	0.03	0.006	0.003
HC or VOC	0.34	0.068	0.034
NO_X	4.50	0.90	0.45
SO_2	21.26	4.25	2.13
PM_{10}	36.12	7.22	3.61

Notes:

a. Geometric mean of low and high health cost estimates from Delucchi (1997a), Table 1-A1.

b. Values for motor vehicles (a) reduced by a factor of 5.

c. Values for motor vehicles (a) reduced by a factor of 10.

Table 4. Environmental Damage Index (EDX) Calculation for an Average 2004 Car

Vehicle Attributes[‡]

Emissions Standard	Tier 2 bin 9
Fuel Economy	29.08 MPG (unadjusted composite), 23.6 MPG (on-road)
Est. Curb Wt.	3,272 lb. (1,484 kg)

(A) Emissions at the Vehicle

Regulated Emissions (by species)	Emission Standard (grams/mile)	Implied Adjustment Factor[†]	Real-World Emissions (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
CO	3.4	3.28	11.1	0.03	0.037
HC	0.075	3.37	0.25	0.34	0.009
NO_X	0.2	2.79	0.56	4.50	0.252
PM_{10}	0.06	0.28	0.02	36.12	0.061

Fuel-Dependent Emissions (by species)	Emission Factor (grams/gallon)	Emissions Rate (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
Evaporative HC[¤]	--	--	0.34	--
SO_X	1.62	0.07	21.26	0.146
CH_4	4.43	0.19	--*	
N_2O	3.25	0.14	--*	
CO_2	8200	347	--*	

Subtotal (a): health-related pollution impacts at the vehicle (cents/mile) 0.504

(B) Emissions from the Fuel Supply Cycle

Fuel-Dependent Emissions (by species)	Emission Factor (grams/gallon)	Emissions Rate (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
CO	6.25	0.26	0.007	0.0002
HC	6.13	0.26	0.068	0.002
NO_X	8.50	0.36	0.90	0.032
PM_{10}	0.96	0.04	7.22	0.029
SO_X	9.88	0.42	4.25	0.178
CH_4	16.6	0.70	--*	
N_2O	0.18	0.01	--*	
CO_2	2450	104	--*	

Subtotal (b): health-related pollution impacts from fuel supply (cents/mile) 0.241

[‡] The Average MY2004 Car was selected as the actual light-duty vehicle most closely matching both fuel economy and vehicle weight estimates as identified in Hellman and Heavenrich (2003). This year, the Average Car is a 2004 Mazda 6, 2.3L 4-cyl, auto stk, with labeled fuel economy of 22/29 MPG (city/hwy) and inertial test weight (ITW) of 3500 lb. Based on analysis of the model year 2004 passenger car fleet, Tier 2 bin 9 was selected as the most representative emissions standard.

[†] Ratio of estimated real-world emissions to emissions standard, resulting from the procedure described under "Vehicle Emissions" in the text.

[¤] Evaporative hydrocarbon emissions are modeled by MOBILE6, but not separately specified. For accounting purposes, they are included here under regulated hydrocarbons.

[*] Greenhouse gas with negligible health damage; these emissions are incorporated on the following page, in part (e).

Table 4. EDX Calculation for an Average 2004 Car (continued)

(C) Emissions Embodied in the Vehicle

Species	Emissions Factor (grams/mile per tonne)	Emissions Rate (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
NO_X	0.198	0.29	0.90	0.026
PM_{10}	0.0283	0.04	7.22	0.030
SO_X	0.243	0.36	4.25	0.153
CO_2	56.0	83.11	--*	

Subtotal (c): health-related pollution impacts from production phase (cents/mile) **0.210**

(D) Greenhouse Gas Emissions from all Sources

source: **Species**	At Vehicle (grams/mile)	Fuel Cycle (grams/mile)	Embodied (grams/mile)	Global Warming Potential (GWP)	CO_2-Equiv. (Grams/Mile)
CO_2	346.79	103.62	83.11	1	533.52
HC	0.25	0.26		2	1.02
NO_X	0.56	0.36	0.29	4	4.85
CO	11.14	0.26		5	57.03
CH_4	0.19	0.70		22	19.59
N_2O	0.14	0.01		355	51.50
Sum weighted by GWP	458.16	125.07	84.29		

Total CO_2-equivalent GHG emissions, grams per mile: 667.52

Assumed damage cost factor for GHG emissions, per kg CO_2-equivalent: $0.0171

Subtotal (d): GHG impacts (cents/mile) **1.141**

(E) Summary of EDX Calculation for an Average 2004 Car

Environmental Impact	Life Cycle Cost (cents/mile)
(a) At the vehicle health-related pollution	0.504
(b) Fuel cycle health-related pollution	0.241
(c) Embodied health-related pollution	0.210
Subtotal, health-related pollution (criteria emissions) impacts	0.956
(d) Greenhouse gas impacts	1.141
TOTAL Environmental Damage Index (EDX)	**2.10**
Corresponding MY2004 Green Score	**32**

Table 5. Environmental Damage Index (EDX) Calculation for an Avg. 2004 Light Truck

Vehicle Attributes[‡]

Emissions Standard	Tier 2 bin 10
Fuel Economy	20.88 MPG (unadjusted composite), 16.7 MPG (on-road)
Mass	4,272 lb. (1,938 kg)

(A) Emissions at the Vehicle

Regulated Emissions (by species)	Emission Standard (grams/mile)	Implied Adjustment Factor[†]	Real-World Emissions (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
CO	3.4	3.17	10.8	0.03	0.036
HC	0.125	2.78	0.35	0.34	0.012
NO_X	0.4	2.34	0.94	4.50	0.421
PM_{10}	0.08	0.27	0.02	36.12	0.077

Fuel-Dependent Emissions (by species)	Emission Factor (grams/gallon)	Emissions Rate (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
Evaporative HC[¤]	--	--	0.34	--
SO_X	1.62	0.10	21.26	0.206
CH_4	4.43	0.27	--*	
N_2O	3.25	0.19	--*	
CO_2	8200	491	--*	

Subtotal (a): health-related pollution impacts at the vehicle (cents/mile) **0.752**

(B) Emissions from the Fuel Supply Cycle

Fuel-Dependent Emissions (by species)	Emission Factor (grams/gallon)	Emissions Rate (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
CO	6.25	0.37	0.007	0.0003
HC	6.13	0.37	0.068	0.002
NO_X	8.50	0.51	0.90	0.046
PM_{10}	0.96	0.06	7.22	0.041
SO_X	9.88	0.59	4.25	0.252
CH_4	16.6	1.00	--*	
N_2O	0.18	0.01	--*	
CO_2	2450	147	--*	

Subtotal (b): health-related pollution impacts from fuel supply (cents/mile) **0.342**

[‡] The Average MY2004 Light Truck was selected as the actual light-duty truck most closely matching both fuel economy and vehicle weight estimates as identified in Hellman and Heavenrich (2003). This year, the Average Light Truck is a 2004 Nissan XTerra, 3.3L 6-cyl, auto, 4wd, with labeled fuel economy of 16/20 MPG (city/hwy) and inertial test weight (ITW) of 4500 lb. Based on analysis of the model year 2004 light truck fleet, Tier 2 bin 10 was selected as the most representative emissions standard.

[†] Ratio of estimated real-world emissions to emissions standard, resulting from the procedure described under "Vehicle Emissions" in the text.

[¤] Evaporative hydrocarbon emissions are modeled by MOBILE6, but not separately specified. For accounting purposes, they are included here under regulated hydrocarbons.

[*] Greenhouse gas with negligible health damage; these emissions are incorporated on the following page, in part (e).

Table 5. EDX Calculation for an Average 2004 Light Truck (continued)

(C) Emissions Embodied in the Vehicle

Species	Emissions Factor (grams/mile per tonne)	Emissions Rate (grams/mile)	Damage Cost ($/kg)	Life Cycle Cost (cents/mile)
NO_X	0.198	0.38	0.90	0.035
PM_{10}	0.0283	0.05	7.22	0.040
SO_X	0.243	0.47	4.25	0.200
CO_2	56.0	108.51	--*	
Subtotal (c): health-related pollution impacts from production phase (cents/mile)				**0.274**

(D) Greenhouse Gas Emissions from all Sources

source: **Species**	At Vehicle (grams/mile)	Fuel Cycle (grams/mile)	Embodied (grams/mile)	Global Warming Potential (GWP)	CO_2-Equiv. Grams/Mile
CO_2	490.94	146.68	108.51	1	746.14
HC	0.35	0.37		2	1.43
NO_X	0.94	0.51	0.38	4	7.32
CO	10.78	0.37		5	55.77
CH_4	0.27	1.00		22	27.74
N_2O	0.19	0.01		355	72.90
Sum weighted by GWP	624.20	177.05	110.05		
Total CO_2-equivalent GHG emissions, grams per mile:					911.30
Assumed damage cost factor for GHG emissions, per kg CO_2-equivalent:					$0.0171
Subtotal (d): GHG impacts (cents/mile)					**1.558**

(E) Summary of EDX Calculation for an Average 2004 Light Truck

Environmental Impact	Life Cycle Cost (cents/mile)
(a) At the vehicle health-related pollution	0.752
(b) Fuel cycle health-related pollution	0.342
(c) Embodied health-related pollution	0.274
Subtotal, health-related pollution (criteria emissions) impacts	1.368
(d) Greenhouse gas impacts	1.558
TOTAL Environmental Damage Index (EDX)	**2.93**
Corresponding MY2004 Green Score	**21**

Table 6. Percentile Guidelines and Symbols for Within-Class Vehicle Rankings

Percentile Guidelines	Class Ranking	Symbol
95% +	Superior [a]	✓
80–95%	Above Average	▲
35–80%	Average	○
15–35%	Below Average	▽
0–15%	Inferior	✖

Notes:

a. For a Superior ranking, a vehicle must also have a Green Score of no less than 27, corresponding to the MY2004 combined car-truck average EDX of 2.44¢/mi.

Table 7. Estimation of 50,000-mile LEV II-SULEV emission standards

Durability (mi)	Emission Category	CO (g/mi)	NMOG (g/mi)	NOx (g/mi)
120,000	LEV II-LEV	4.2	0.09	0.07
50,000	LEV II-LEV	3.4	0.075	0.05
Ratio:		*1.24*	*1.20*	*1.40*
120,000	LEV II-ULEV	2.1	0.055	0.07
50,000	LEV II-ULEV	1.7	0.04	0.05
Ratio:		*1.24*	*1.38*	*1.40*
120,000	LEV II-SULEV	1.0	0.01	0.02
Ratio:		*1.24*	*1.38*	*1.40*
50,000 Estimated	LEV II-SULEV	0.81	0.007	0.014

Table 8. Vehicle Survival Miles (as a Percentage of Lifetime Travel) Over Assumed 25-Year Lifetime

Age	LDV	LDT1	LDT2	LDT3	LDT4
0	8.6%	10.2%	10.2%	10.4%	10.4%
1	8.3%	9.8%	9.8%	9.8%	9.8%
2	7.9%	9.2%	9.2%	9.2%	9.2%
3	7.5%	8.6%	8.6%	8.5%	8.5%
4	7.1%	8.1%	8.1%	7.9%	7.9%
5	6.8%	7.4%	7.4%	7.2%	7.2%
6	6.4%	6.7%	6.7%	6.5%	6.5%
7	5.9%	6.0%	6.0%	5.8%	5.8%
8	5.4%	5.4%	5.4%	5.2%	5.2%
9	4.9%	4.7%	4.7%	4.6%	4.6%
10	4.4%	4.2%	4.2%	4.1%	4.1%
11	4.0%	3.6%	3.6%	3.5%	3.5%
12	3.6%	3.1%	3.1%	3.1%	3.1%
13	3.2%	2.6%	2.6%	2.6%	2.6%
14	2.8%	2.2%	2.2%	2.3%	2.3%
15	2.4%	1.8%	1.8%	1.9%	1.9%
16	2.1%	1.5%	1.5%	1.6%	1.6%
17	1.8%	1.2%	1.2%	1.3%	1.3%
18	1.6%	1.0%	1.0%	1.1%	1.1%
19	1.3%	0.8%	0.8%	0.9%	0.9%
20	1.1%	0.6%	0.6%	0.7%	0.7%
21	0.9%	0.5%	0.5%	0.6%	0.6%
22	0.8%	0.4%	0.4%	0.5%	0.5%
23	0.6%	0.3%	0.3%	0.4%	0.4%
24	0.5%	0.2%	0.2%	0.3%	0.3%

Notes:
Results computed from MOBILE6 car and light truck characterization data (documented in EPA 2001a, and specified in the MOBILE6 model output), and car and light truck survival data (documented in Davis and Diegel 2002).

Table 9. Corresponding Tier 2 bins of LEV I-LEV and LEV I-ULEV Emission Standards

Pollutant	Emission Standard	Emission Level (g/mi)	Corresponding Tier 2 Bin(s)
CO	LEV I	3.4	5-9
	ULEV I	1.7	2-4
HC	LEV I	0.075	5-7
	ULEV I	0.04	3
NO_x	LEV I	0.20	9
	ULEV I	0.20	9

Table 10. 120,000-Mile Extrapolation of LEV I-LEV and LEV I-ULEV Emission Standards

Pollutant	Durability Vehicle Basis (mi.)	LEV I-LEV Standard (g/mi)	LEV I-ULEV Standard (g/mi)
CO	50,000	3.4	1.7
	100,000	4.2	2.1
	120,000 (estimated)	4.52	2.26
HC	50,000	0.075	0.04
	100,000	0.09	0.055
	120,000 (estimated)	0.096	0.061
NO_x	50,000	0.2	0.2
	100,000	0.3	0.3
	120,000 (estimated)	0.34	0.34

Figure 1. Lifetime Average In-Use Tailpipe Emissions for Gasoline Cars

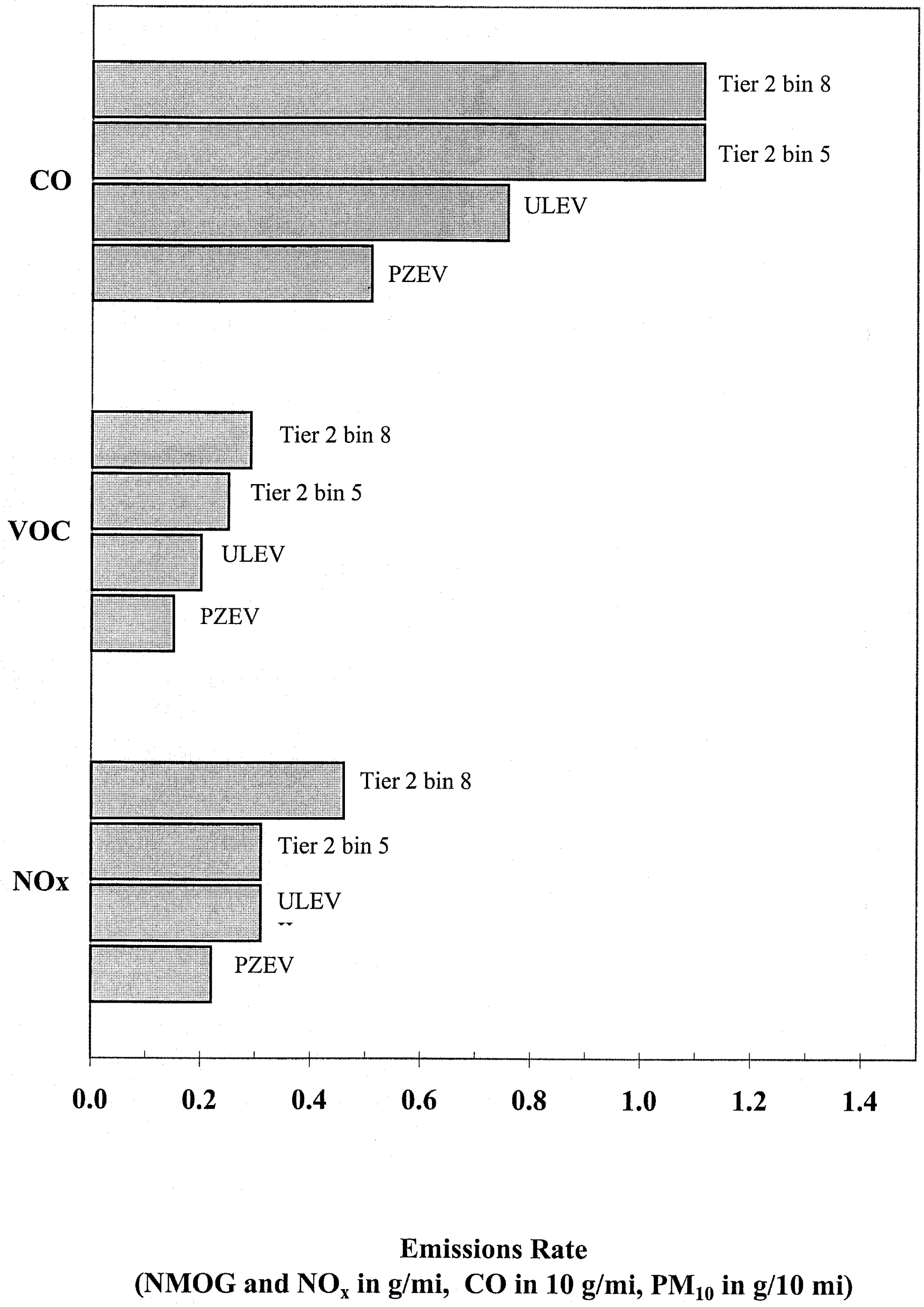
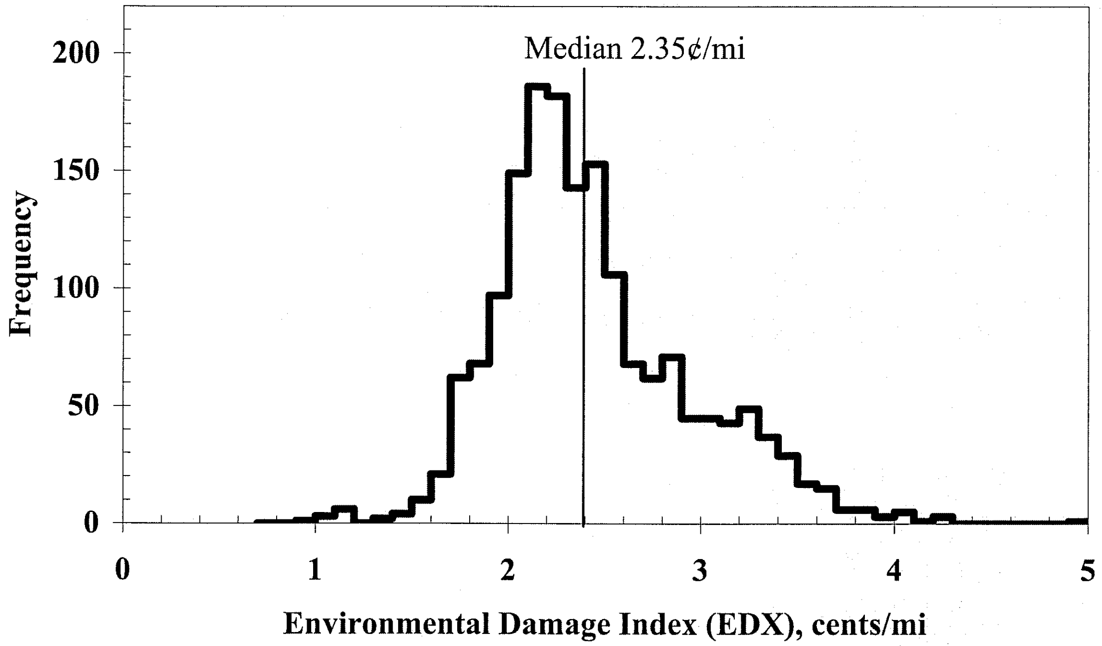


Figure 2. Distribution of Environmental Damage Index for Model Year 2004

(a) Cars and Light Trucks Combined



(b) Cars and Light Trucks Shown Separately

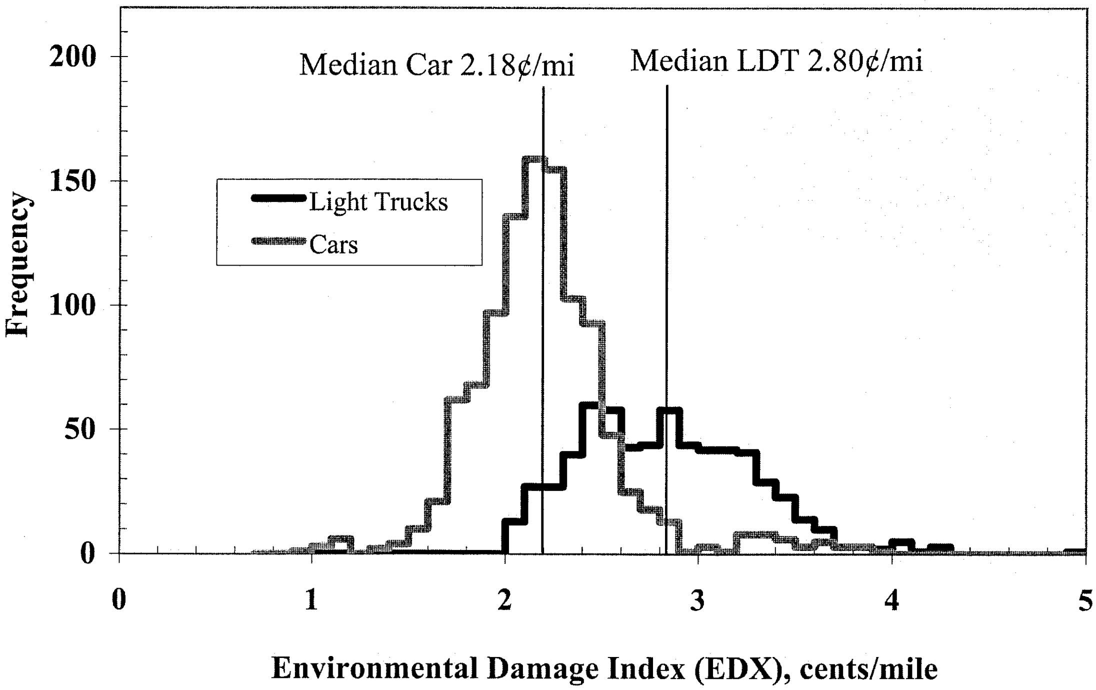
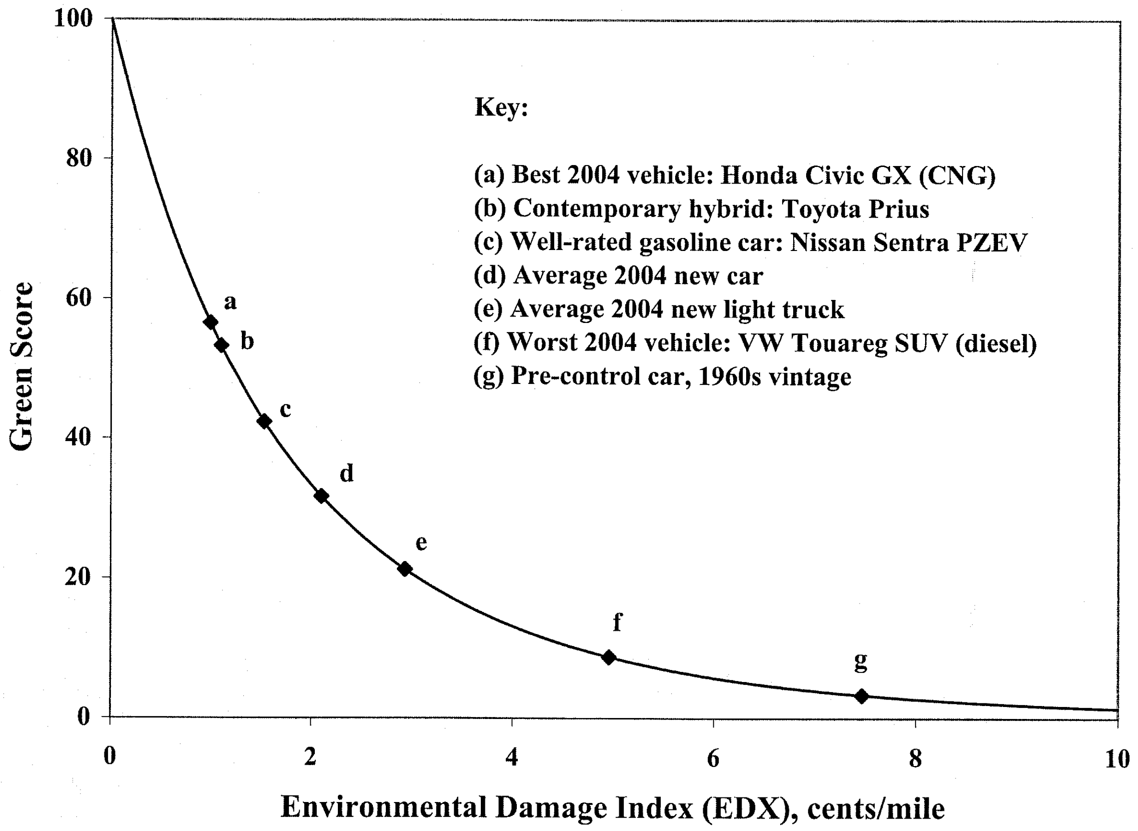


Figure 3. Green Score vs. Environmental Damage Index, with Example Vehicles



Appendix A

DETAILS OF EMISSIONS CHARACTERIZATION ESTIMATES

Lifetime Average Tailpipe Emissions Estimates

This multi-part table documents our estimates of tailpipe emissions from gasoline, compressed natural gas (CNG), and diesel vehicles according to fuel type and pollutant. All vehicles within a given light-duty class, fuel type, and emission standard are assumed to have the same real-world emissions. Real-world (in-use) emissions performance is known to differ significantly among models that meet the same nominal standard. However, an accepted procedure does not exist for measuring and estimating such differences for the purpose of discriminating among models.

Index to Sub-Tables:

A1(a)	Gasoline Vehicles: CO
A1(b)	Gasoline Vehicles: HC
A1(c)	Gasoline Vehicles: NO_x
A1(d)	Gasoline Vehicles: PM_{10}
A2(a)	CNG Vehicles: CO
A2(b)	CNG Vehicles: HC
A2(c)	CNG Vehicles: NO_x
A2(d)	CNG Vehicles: PM_{10}
A3(a)	Diesel Vehicles: CO
A3(b)	Diesel Vehicles: HC
A3(c)	Diesel Vehicles: NO_x
A3(d)	Diesel Vehicles: PM_{10}

Weight Classifications for Federally Certified Vehicles		Median ITW	Notes:
LDV	All passenger cars	3500	a
LDT1	GVW 0-6000 lb. and LVW 0-3750 lb	3500	a
LDT2	GVW 0-6000 lb. and LVW 3751-5750 lb	4500	a
LDT3	GVW 6001-8500 lb. and ALVW 0-5750 lb	5250	b
LDT4	GVW 6001-8500 lb. and ALVW 5751-8500 lb	6000	a
Class 2b	GVW 8501-10000 lb	6300	c, d

Weight Classifications for California Certified Vehicles		Median ITW	Notes:
PC	All passenger cars	3500	a
LDT1-CA	GVW 0-6000 lb, LVW 0-3750 lb	3500	a
LDT2-CA	GVW 0-6000 lb, LVW 3751-5750 lb	4500	a
MDV2-CA	GVW 6001-14000 lb, ALVW 3751-5750 lb	5250	b
MDV3-CA	GVW 6001-14000 lb, ALVW 5751-8500 lb	6000	a
MDV4-CA	GVW 6001-14000 lb, ALVW 8501-10000 lb	6300	c, d

VCW (Vehicle Curb Weight): The weight of the vehicle with all of its tanks full and components included but no passenger or luggage (load) adjustments.

GVW (Gross Vehicle Weight): The value specified by the manufacturer as a vehicle's maximum design loaded weight.

LVW (Loaded Vehicle Weight): The vehicle curb weight plus 300 lb. LVW = VCW + 300 lb.

ALVW (Average Loaded Vehicle Weight): The average of the vehicle's curb weight and gross vehicle weight:
ALVW = (VCW + GVW) / 2

Notes: See following page.

Lifetime Average Tailpipe Emissions Estimates (continued)

All Tier 1, Tier 2, LEV II, and ULEV II CO, HC, and NO_x emissions estimates for gasoline vehicles (LDV, LDT1, LDT2, LDT3, and LDT4) are modeled using the MOBILE6.2 emission factor model. These estimates include off-cycle effects; thus off-cycle adjustments are not necessary for these pollutants. Emissions estimates for remaining standards (e.g., SULEV II, PZEV, LEV I, ULEV I), pollutants (PM) fuels (CNG, diesel), and vehicle classes (Class 2b trucks) are determined as described below and shown in the sub-tables.

Scaling Emissions Factors from Cars to Light-duty Trucks (diesel)

Source of emissions

Off-cycle	Assumes 28% off-cycle, 78% in-use; see Appendix Tables A3(a)-A3(d)

Scaling Emissions Factors from LDT4s to Class 2b Trucks

Source of emissions

Lifetime Avg. Estimate	Scales with ratio of HDT weight : LDV4 weight (6300 / 6000 = 1.05)

Notes:

a. Median ITW for each weight class is derived from MY1999 data provided by EPA to ACEEE
b. We assume the midpoint between LDT2 and LDT4
c. Based on a review of industry HDT specifications, HDT weight is assumed to be 300 lb. greater than comparable LDT4s for the purpose of creating an HDT load-scaling factor.
d. HDT emissions are scaled by load to LDT4 emissions. The ratio here is HDT weight/LDT4 weight (1.05).

APPENDIX TABLE A1(a):

Gasoline Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Carbon Monoxide (CO)

	LDV	LDT1	LDT2	LDT3	LDT4	2b
Tier 1 [a]	10.03	9.88	11.44	11.96	12.28	12.90
bin 11 [a]	16.38	16.14	15.85	15.07	14.24	14.95
bin 10 [a]	11.14	10.98	10.78	13.26	12.53	13.16
bin 9 [a]	11.14	10.98	10.78	11.22	10.66	11.19
bin 8 [a]	11.14	10.98	10.78	11.22	10.66	11.19
bin 7 [a]	11.14	10.98	10.78	11.22	10.66	11.19
bin 6 [a]	11.14	10.98	10.78	11.22	10.66	11.19
bin 5 [a]	11.14	10.98	10.78	11.22	10.66	11.19
bin 4 [a]	7.57	7.38	7.40	7.75	7.47	7.85
bin 3 [a]	7.57	7.38	7.40	7.75	7.47	7.85
bin 2 [a]	7.57	7.38	7.40	7.75	7.47	7.85
bin 1 [a]	-	-	-	-	-	-
LEV I [b]	11.99	11.81	11.60	12.08	11.47	12.05
ULEV I [b]	8.15	7.94	7.96	8.34	8.04	8.45
LEV II [a]	11.14	10.98	10.78	11.22	10.66	11.19
ULEV II [a]	7.57	7.38	7.40	7.75	7.47	7.85
SULEV II [c]	5.40	5.20	5.32	5.67	5.55	5.82
PZEV [d]	5.09	4.89	5.03	5.37	5.27	5.53
ZEV [a]	-	-	-	-	-	-

Notes:

a. Emissions estimates computed through MOBILE6.2 modeling.

b. Estimated based on corresponding Tier 2 bins, with adjustments to reflect greater deterioration; see Tables 9 and 10.

c. Emissions estimates computed through MOBILE6.2 modeling; as noted in the text, results downward adjusted by the ratios specified in Table 7 to estimate 50,000-mile performance.

d. Emissions estimates computed through MOBILE6.2 modeling; as noted in the text, results downward adjusted to reflect 150,000-mile durability compliance.

APPENDIX TABLE A1(b):

Gasoline Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Hydrocarbons (HC)

	LDV	LDT1	LDT2	LDT3	LDT4	2b
Tier 1 [a]	0.48	0.50	0.59	0.99	1.13	1.19
bin 11 [a]	0.51	0.54	0.54	0.81	0.90	0.95
bin 10 [a]	0.33	0.35	0.35	0.67	0.74	0.78
bin 9 [a]	0.25	0.27	0.31	0.62	0.62	0.65
bin 8 [a]	0.29	0.31	0.31	0.59	0.58	0.61
bin 7 [a]	0.25	0.27	0.27	0.47	0.47	0.49
bin 6 [a]	0.25	0.27	0.27	0.47	0.47	0.49
bin 5 [a]	0.25	0.27	0.27	0.47	0.47	0.49
bin 4 [a]	0.21	0.24	0.23	0.42	0.41	0.44
bin 3 [a]	0.20	0.22	0.22	0.39	0.39	0.41
bin 2 [a]	0.15	0.17	0.17	0.31	0.31	0.33
bin 1 [a]	-	-	-	-	-	-
LEV I [b]	0.27	0.29	0.29	0.50	0.50	0.53
ULEV I [b]	0.22	0.24	0.24	0.43	0.43	0.45
LEV II [a]	0.25	0.27	0.27	0.47	0.47	0.49
ULEV II [a]	0.20	0.22	0.22	0.39	0.39	0.41
SULEV II [c]	0.16	0.18	0.18	0.33	0.33	0.35
PZEV [d]	0.15	0.17	0.17	0.33	0.33	0.35
ZEV [a]	-	-	-	-	-	-

Notes:

a. Emissions estimates computed through MOBILE6.2 modeling.

b. Estimated based on corresponding Tier 2 bins, with adjustments to reflect greater deterioration; see Tables 9 and 10.

c. Emissions estimates computed through MOBILE6.2 modeling; as noted in the text, results downward adjusted by the ratios specified in Table 7 to estimate 50,000-mile performance.

d. Emissions estimates computed through MOBILE6.2 modeling; as noted in the text, results downward adjusted to reflect 150,000-mile durability compliance.

APPENDIX TABLE A1(c):

Gasoline Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Nitrogen Oxides (NO_x)

	LDV	LDT1	LDT2	LDT3	LDT4	2b
Tier 1 [a]	0.81	0.85	1.28	1.34	1.91	2.01
bin 11 [a]	1.33	1.41	1.40	1.51	1.52	1.60
bin 10 [a]	0.89	0.94	0.94	1.00	1.01	1.07
bin 9 [a]	0.56	0.60	0.60	0.67	0.69	0.72
bin 8 [a]	0.46	0.50	0.50	0.57	0.59	0.62
bin 7 [a]	0.41	0.45	0.45	0.52	0.54	0.57
bin 6 [a]	0.36	0.40	0.40	0.47	0.49	0.51
bin 5 [a]	0.31	0.35	0.35	0.42	0.44	0.46
bin 4 [a]	0.28	0.31	0.32	0.38	0.40	0.43
bin 3 [a]	0.26	0.30	0.31	0.37	0.39	0.41
bin 2 [a]	0.25	0.29	0.29	0.36	0.38	0.40
bin 1 [a]	-	-	-	-	-	-
LEV I [b]	0.63	0.68	0.68	0.76	0.78	0.82
ULEV I [b]	0.63	0.68	0.68	0.76	0.78	0.82
LEV II [a]	0.31	0.35	0.35	0.42	0.44	0.46
ULEV II [a]	0.31	0.35	0.35	0.42	0.44	0.46
SULEV II [c]	0.23	0.26	0.26	0.32	0.34	0.36
PZEV [d]	0.22	0.25	0.26	0.32	0.34	0.35
ZEV [a]	-	-	-	-	-	-

Notes:

a. Emissions estimates computed through MOBILE6.2 modeling.

b. Estimated based on corresponding Tier 2 bins, with adjustments to reflect greater deterioration; see Tables 9 and 10.

c. Emissions estimates computed through MOBILE6.2 modeling; as noted in the text, results downward adjusted by the ratios specified in Table 7 to estimate 50,000-mile performance.

d. Emissions estimates computed through MOBILE6.2 modeling; as noted in the text, results downward adjusted to reflect 150,000-mile durability compliance.

APPENDIX TABLE A1(d):

Gasoline Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Particulate Matter (PM_{10})

	LDV [a]	LDT1 [b]	LDT2 [b]	LDT3 [c]	LDT4 [d]	2b [e]
Tier 1	0.017	0.021	0.021	0.040 [f]	0.048 [f]	0.050
bin 11	0.017	0.021	0.021	0.040 [f]	0.048 [f]	0.050
bin 10	0.017	0.021	0.021	0.040 [f]	0.048 [f]	0.050
bin 9	0.017	0.021	0.021	0.040 [f]	0.048 [f]	0.050
bin 8	0.017	0.021	0.021	0.027	0.032	0.033
bin 7	0.017	0.021	0.021	0.027	0.032	0.033
bin 6	0.017	0.021	0.021	0.027	0.032	0.033
bin 5	0.017	0.021	0.021	0.027	0.032	0.033
bin 4	0.017	0.021	0.021	0.027	0.032	0.033
bin 3	0.017	0.021	0.021	0.027	0.032	0.033
bin 2	0.017	0.021	0.021	0.027	0.032	0.033
bin 1	-	-	-	-	-	-
LEV I	0.017	0.021	0.021	0.027	0.032	0.033
ULEV I	0.017	0.021	0.021	0.027	0.032	0.033
LEV II	0.017	0.021	0.021	0.027	0.032	0.033
ULEV II	0.017	0.021	0.021	0.027	0.032	0.033
SULEV II	0.017	0.021	0.021	0.027	0.032	0.033
PZEV	0.017	0.021	0.021	0.027	0.032	0.033
ZEV	-	-	-	-	-	-

Notes:

a. LDV PM_{10} emissions estimates computed as midpoint of Delucchi (2001) and Wang (2003) estimates of 0.022 and 0.012 g/mi, respectively.

b. LDT1 and LDT2 PM_{10} emission estimates computed using LDV estimates and the ratio of gasoline LDV (0.012 g/mi), LDT1 (0.015 g/mi), and LDT2 (0.015 g/mi) estimates specified by Wang (2003): 0.017 * (0.015 / 0.012) = 0.021g/mi.

c. LDT3 PM_{10} emission estimates for vehicles certified to Tier 2 bin 8 and cleaner are computed using LDT2 estimates and the ratio of 2003 LDT3 (0.10 g/mi) to LDT2 (0.08 g/mi) PM_{10} emission standards specified in DeCicco and Kliesch (2002): 0.021 * (0.10 / 0.08) = 0.027g/mi.

d. LDT4 PM_{10} emission estimates for vehicles certified to Tier 2 bin 8 and cleaner are computed using LDT2 estimates and the ratio of 2003 LDT4 (0.12 g/mi) to LDT2 (0.08 g/mi) PM_{10} emission standards specified in DeCicco and Kliesch (2002): 0.021 * (0.12 / 0.08) = 0.032g/mi.

e. Class 2b Truck PM_{10} emission estimates computed as being 5% higher than LDT4 estimates.

f. PM_{10} emission estimates for LDT3s and LDT4s certified to Tier 2 bin 9 and higher are deemed 50 percent greater than corresponding Tier 2 bin 8 levels.

APPENDIX TABLE A2(a):

CNG Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Carbon Monoxide (CO)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [d]
Tier 1	N/A	N/A	N/A	N/A	N/A	N/A
bin 11 [c]	12.98	12.98	16.80	33.60	38.18	40.09
bin 10 [c]	8.83	8.83	11.42	22.85	25.96	27.26
bin 9 [c]	8.83	8.83	11.42	22.85	25.96	27.26
bin 8 [c]	8.83	8.83	11.42	22.85	25.96	27.26
bin 7 [c]	8.83	8.83	11.42	22.85	25.96	27.26
bin 6 [c]	8.83	8.83	11.42	22.85	25.96	27.26
bin 5 [c]	8.83	8.83	11.42	22.85	25.96	27.26
bin 4 [c]	5.45	5.45	7.06	14.11	16.04	16.84
bin 3 [c]	5.45	5.45	7.06	14.11	16.04	16.84
bin 2 [c]	5.45	5.45	7.06	14.11	16.04	16.84
bin 1	-	-	-	-	-	-
LEV I [c]	8.83	8.83	11.42	22.85	25.96	27.26
ULEV I	4.41 [a]	4.41 [b]	5.71 [b]	11.42 [b]	12.98 [b]	13.63
LEV II [c]	8.83	8.83	11.42	22.85	25.96	27.26
ULEV II [c]	4.41	4.41	5.71	11.42	12.98	13.63
SULEV II [c]	2.60	2.60	3.36	6.72	7.64	8.02
PZEV [c]	2.60	2.60	3.36	6.72	7.64	8.02
ZEV	-	-	-	-	-	-

Notes:

a. Near-term CNG light duty vehicle emissions, as specified Wang (2003).

b. Estimates for LDT1-LDT4 are scaled up from the ULEV I LDV estimates, based upon a ratio of emission standards for the LDV and LDT classes specified in Appendix Table D1.

c. LDV estimates for each emission certification are computed by multiplying the respective emission standard (as specified in Appendix Table D1) by the ratio of ULEV I emissions to the ULEV I standard (4.41 / 1.7). LDT1-LDT4 estimates are computed by multiplying the LDV estimate for each emission certification by the ratio of ULEV I LDTx-to-LDV real-world emissions.

d. Class 2b Truck CO emission estimates computed as being 5% higher than LDT4 estimates.

APPENDIX TABLE A2(b):

CNG Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Hydrocarbons (HC)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [d]
Tier 1	N/A	N/A	N/A	N/A	N/A	N/A
bin 11 [c]	0.16	0.16	0.20	0.39	0.46	0.48
bin 10 [c]	0.10	0.10	0.13	0.25	0.29	0.31
bin 9 [c]	0.06	0.06	0.08	0.15	0.18	0.18
bin 8 [c]	0.08	0.08	0.10	0.20	0.23	0.25
bin 7 [c]	0.06	0.06	0.08	0.15	0.18	0.18
bin 6 [c]	0.06	0.06	0.08	0.15	0.18	0.18
bin 5 [c]	0.06	0.06	0.08	0.15	0.18	0.18
bin 4 [c]	0.06	0.06	0.07	0.14	0.16	0.17
bin 3 [c]	0.04	0.04	0.06	0.11	0.13	0.14
bin 2 [c]	0.01	0.01	0.01	0.02	0.02	0.02
bin 1	-	-	-	-	-	-
LEV I [c]	0.06	0.06	0.08	0.15	0.18	0.18
ULEV I	0.03 [a]	0.03 [b]	0.04 [b]	0.08 [b]	0.09 [b]	0.10
LEV II [c]	0.06	0.06	0.08	0.15	0.18	0.18
ULEV II [c]	0.03	0.03	0.04	0.08	0.09	0.10
SULEV II [c]	0.01	0.01	0.01	0.02	0.02	0.02
PZEV [c]	0.01	0.01	0.01	0.02	0.02	0.02
ZEV	-	-	-	-	-	-

Notes:

a. Near-term CNG light duty vehicle emissions, as specified Wang (2003).

b. Estimates for LDT1-LDT4 are scaled up from the ULEV I LDV estimates, based upon a ratio of emission standards for the LDV and LDT classes specified in Appendix Table D2.

c. LDV estimates for each emission certification are computed by multiplying the respective emission standard (as specified in Appendix Table D2) by the ratio of ULEV I emissions to the ULEV I standard (4.41 / 1.7). LDT1-LDT4 estimates are computed by multiplying the LDV estimate for each emission certification by the ratio of ULEV I LDTx-to-LDV real-world emissions.

d. Class 2b Truck HC emission estimates computed as being 5% higher than LDT4 estimates.

APPENDIX TABLE A2(c):

CNG Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Nitrogen Oxides (NO_x)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [d]
Tier 1	N/A	N/A	N/A	N/A	N/A	N/A
bin 11 [c]	0.74	0.74	1.49	1.49	2.23	2.34
bin 10 [c]	0.50	0.50	0.99	0.99	1.49	1.56
bin 9 [c]	0.25	0.25	0.50	0.50	0.74	0.78
bin 8 [c]	0.17	0.17	0.35	0.35	0.52	0.55
bin 7 [c]	0.14	0.14	0.27	0.27	0.41	0.43
bin 6 [c]	0.10	0.10	0.20	0.20	0.30	0.31
bin 5 [c]	0.06	0.06	0.12	0.12	0.19	0.20
bin 4 [c]	0.05	0.05	0.10	0.10	0.15	0.16
bin 3 [c]	0.04	0.04	0.07	0.07	0.11	0.12
bin 2 [c]	0.02	0.02	0.05	0.05	0.07	0.08
bin 1	-	-	-	-	-	-
LEV I [c]	0.25	0.25	0.50	0.50	0.74	0.78
ULEV I	0.25 [a]	0.25 [b]	0.50 [b]	0.50 [b]	0.74 [b]	0.78
LEV II [c]	0.06	0.06	0.12	0.12	0.19	0.20
ULEV II [c]	0.06	0.06	0.12	0.12	0.19	0.20
SULEV II [c]	0.02	0.02	0.05	0.05	0.07	0.08
PZEV [c]	0.02	0.02	0.05	0.05	0.07	0.08
ZEV	-	-	-	-	-	-

Notes:

a. Near-term CNG light duty vehicle emissions, as specified Wang (2003).

b. Estimates for LDT1-LDT4 are scaled up from the ULEV I LDV estimates, based upon a ratio of emission standards for the LDV and LDT classes specified in Appendix Table D3.

c. LDV estimates for each emission certification are computed by multiplying the respective emission standard (as specified in Appendix Table D3) by the ratio of ULEV I emissions to the ULEV I standard (4.41 / 1.7). LDT1-LDT4 estimates are computed by multiplying the LDV estimate for each emission certification by the ratio of ULEV I LDTx-to-LDV real-world emissions.

d. Class 2b Truck NO_x emission estimates computed as being 5% higher than LDT4 estimates.

APPENDIX TABLE A2(d):

CNG Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Particulate Matter (PM10)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [d]
Tier 1	N/A	N/A	N/A	N/A	N/A	N/A
bin 11 [c]	0.003	0.003	0.004	0.004	0.005	0.005
bin 10 [c]	0.002	0.002	0.003	0.003	0.003	0.003
bin 9 [c]	0.002	0.002	0.002	0.002	0.002	0.002
bin 8 [c]	0.001	0.001	0.001	0.001	0.001	0.001
bin 7 [c]	0.001	0.001	0.001	0.001	0.001	0.001
bin 6 [c]	0.000	0.000	0.000	0.000	0.000	0.000
bin 5 [c]	0.000	0.000	0.000	0.000	0.000	0.000
bin 4 [c]	0.000	0.000	0.000	0.000	0.000	0.000
bin 3 [c]	0.000	0.000	0.000	0.000	0.000	0.000
bin 2 [c]	0.000	0.000	0.000	0.000	0.000	0.000
bin 1	-	-	-	-	-	-
LEV I [c]	0.002	0.002	0.003	0.003	0.003	0.003
ULEV I	0.001 [a]	0.001 [b]	0.001 [b]	0.001 [b]	0.002 [b]	0.002
LEV II [c]	0.000	0.000	0.000	0.000	0.000	0.000
ULEV II [c]	0.000	0.000	0.000	0.000	0.000	0.000
SULEV II [c]	0.000	0.000	0.000	0.000	0.000	0.000
PZEV [c]	0.000	0.000	0.000	0.000	0.000	0.000
ZEV	-	-	-	-	-	-

Notes:

a. Near-term CNG light duty vehicle emissions, as specified Wang (2003).

b. Estimates for LDT1-LDT4 are scaled up from the ULEV I LDV estimates, based upon a ratio of emission standards for the LDV and LDT classes specified in Appendix Table D4.

c. LDV estimates for each emission certification are computed by multiplying the respective emission standard (as specified in Appendix Table D4) by the ratio of ULEV I emissions to the ULEV I standard (4.41 / 1.7). LDT1-LDT4 estimates are computed by multiplying the LDV estimate for each emission certification by the ratio of ULEV I LDTx-to-LDV real-world emissions.

d. Class 2b Truck PM_{10} emission estimates computed as being 5% higher than LDT4 estimates.

APPENDIX TABLE A3(a):

Diesel Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Carbon Monoxide (CO)

	LDV	LDT1	LDT2	LDT3	LDT4	2b[c]
Tier 1	N/A	N/A	N/A	2.02[d]	2.20[d]	2.31
bin 11	N/A	N/A	N/A	2.55[a]	2.55[a]	2.68
bin 10	2.11[a]	2.50[a]	2.50[a]	2.25[b]	2.25[b]	2.36
bin 9	2.11[b]	2.50[b]	2.50[b]	1.90[b]	1.91[b]	2.00
bin 8	2.11[b]	2.50[b]	2.50[b]	1.90[b]	1.91[b]	2.00
bin 7	2.11[b]	2.50[b]	2.50[b]	1.90[b]	1.91[b]	2.00
bin 6	2.11[b]	2.50[b]	2.50[b]	1.90[b]	1.91[b]	2.00
bin 5	2.11[b]	2.50[b]	2.50[b]	1.90[b]	1.91[b]	2.00

Notes:

a. "Reference emission factors" computed based on zero-mile levels and deterioration rates specified in EPA (2001b), in conjunction with MOBILE6-specified annual VMT levels. Subsequent on- and off-cycle apportionments are made, as described in the text.

b. Computed based on the reference emission factor (see note "a" above), and gasoline emissions estimates at the respective emission standards. For example, Tier 2 bin 9 diesel LDV CO emissions are estimated by multiplying Tier 2 bin 9 gasoline CO emissions estimate specified in Appendix Table A1(b), (11.14 g/mi), and the ratio of diesel-to-gasoline for the Tier 2 bin 10 reference emission factor (2.11 / 11.14) = 2.11 g/mi.

c. Class 2b Truck PM_{10} emission estimates computed as being 5% higher than LDT4 estimates.

d. Tier 1 emissions estimates computed based on Tier 2 bin 11 emissions estimates and the ratio of Tier 1-to-Tier 2 bin 11 gasoline estimates. For example, diesel LDT3 CO estimates are computed by multiplying Tier 2 bin 11 estimate (2.55 g/mi) and the ratio of Tier 1-to-Tier 2 bin 11 gasoline CO estimate (11.96 / 15.07) = 2.02 g/mi.

APPENDIX TABLE A3(b):

Diesel Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Hydrocarbons (HC)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [c]
Tier 1	N/A	N/A	N/A	1.59 [d]	1.63 [d]	1.71
bin 11	N/A	N/A	N/A	1.30 [a]	1.30 [a]	1.37
bin 10	0.78 [a]	1.25 [a]	1.25 [a]	1.07 [b]	1.07 [b]	1.12
bin 9	0.61 [b]	0.98 [b]	1.11 [b]	0.99 [b]	0.89 [b]	0.93
bin 8	0.69 [b]	1.11 [b]	1.11 [b]	0.94 [b]	0.84 [b]	0.88
bin 7	0.60 [b]	0.97 [b]	0.97 [b]	0.75 [b]	0.68 [b]	0.71
bin 6	0.60 [b]	0.97 [b]	0.97 [b]	0.75 [b]	0.68 [b]	0.71
bin 5	0.60 [b]	0.97 [b]	0.97 [b]	0.75 [b]	0.68 [b]	0.71

Notes:

a. "Reference emission factors" computed based on zero-mile levels and deterioration rates specified in EPA (2001b), in conjunction with MOBILE6-specified annual VMT levels. Subsequent on- and off-cycle apportionments are made, as described in the text.

b. Computed based on the reference emission factor (see note "a" above), and gasoline emissions estimates at the respective emission standards. For example, Tier 2 bin 9 diesel LDV HC emissions are estimated by multiplying Tier 2 bin 9 gasoline HC emissions estimate specified in Appendix Table A1(b), (0.25 g/mi), and the ratio of diesel-to-gasoline for the Tier 2 bin 10 reference emission factor (0.78 / 0.33) = 0.61 g/mi.

c. Class 2b Truck PM_{10} emission estimates computed as being 5% higher than LDT4 estimates.

d. Tier 1 emissions estimates computed based on Tier 2 bin 11 emissions estimates and the ratio of Tier 1-to-Tier 2 bin 11 gasoline estimates. For example, diesel LDT3 HC estimates are computed by multiplying Tier 2 bin 11 estimate (1.30 g/mi) and the ratio of Tier 1-to-Tier 2 bin 11 gasoline HC estimate (0.99 / 0.81) = 1.59 g/mi.

APPENDIX TABLE A3(c):

Diesel Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Nitrogen Oxides (NO_x)

	LDV	LDT1	LDT2	LDT3	LDT4	2b[c]
Tier 1	N/A	N/A	N/A	1.74[d]	2.46[d]	2.58
bin 11	N/A	N/A	N/A	1.96[a]	1.96[a]	2.06
bin 10	1.59[a]	1.92[a]	1.92[a]	1.31[b]	1.31[b]	1.37
bin 9	1.00[b]	1.22[b]	1.24[b]	0.87[b]	0.88[b]	0.93
bin 8	0.82[b]	1.02[b]	1.03[b]	0.74[b]	0.76[b]	0.79
bin 7	0.73[b]	0.91[b]	0.93[b]	0.67[b]	0.69[b]	0.73
bin 6	0.65[b]	0.81[b]	0.83[b]	0.61[b]	0.63[b]	0.66
bin 5	0.56[b]	0.71[b]	0.73[b]	0.54[b]	0.57[b]	0.59

Notes:

a. "Reference emission factors" computed based on zero-mile levels and deterioration rates specified in EPA (2001b), in conjunction with MOBILE6-specified annual VMT levels. Subsequent on- and off-cycle apportionments are made, as described in the text.

b. Computed based on the reference emission factor (see note "a" above), and gasoline emissions estimates at the respective emission standards. For example, Tier 2 bin 9 diesel LDV NO_x emissions are estimated by multiplying Tier 2 bin 9 gasoline NO_x emissions estimate specified in Appendix Table A1(c), (0.56 g/mi), and the ratio of diesel-to-gasoline for the Tier 2 bin 10 reference emission factor (1.59 / 0.89) = 1.00 g/mi.

c. Class 2b Truck PM_{10} emission estimates computed as being 5% higher than LDT4 estimates.

d. Tier 1 emissions estimates computed based on Tier 2 bin 11 emissions estimates and the ratio of Tier 1-to-Tier 2 bin 11 gasoline estimates. For example, diesel LDT3 NO_x estimates are computed by multiplying Tier 2 bin 11 estimate (1.96 g/mi) and the ratio of Tier 1-to-Tier 2 bin 11 gasoline NO_x estimate (1.34 / 1.51) = 1.74 g/mi.

APPENDIX TABLE A3(d):

Diesel Vehicle Lifetime Average In-Use Emission Estimates (g/mi): Particulate Matter (PM_{10})

	LDV	LDT1	LDT2	LDT3	LDT4	2b[d]
Tier 1	N/A	N/A	N/A	0.349[g]	0.418[f]	0.439
bin 11[e]	N/A	N/A	N/A	0.332	0.398	0.418
bin 10	0.142[a]	0.177[a]	0.177[a]	0.221[b]	0.266[c]	0.279
bin 9[e]	0.106	0.133	0.133	0.166	0.199	0.209
bin 8[e]	0.035	0.044	0.044	0.055	0.066	0.070
bin 7[e]	0.035	0.044	0.044	0.055	0.066	0.070
bin 6[e]	0.018	0.022	0.022	0.028	0.033	0.035
bin 5[e]	0.018	0.022	0.022	0.028	0.033	0.035

Notes:

a. Tier 2 bin 10 LDV, LDT1, and LDT2 PM_{10} "reference" emission factors computed by multiplying Tier 2 bin 10 gasoline PM_{10} emissions, specified in Appendix Table A1(d), by the ratio of diesel-to-gasoline emissions (0.10 / 0.012) outlined in Wang (2003).

b. Tier 2 bin 10 LDT3 "reference" emission factor computed by scaling up Tier 2 bin 10 LDT2 estimate by the ratio of 2003 LDT3 (0.10 g/mi) to LDT2 (0.08 g/mi) PM_{10} emission standards, as specified in DeCicco and Kliesch (2002).

c. Tier 2 bin 10 LDT4 "reference" emission factor computed by scaling up Tier 2 bin 10 LDT2 estimate by the ratio of 2003 LDT4 (0.12 g/mi) to LDT2 (0.08 g/mi) PM_{10} emission standards, as specified in DeCicco and Kliesch (2002).

d. Class 2b Truck PM_{10} emission estimates computed as being 5% higher than LDT4 estimates.

e. Emissions estimates for these bins are computed by multiplying the Tier 2 bin 10 "reference" emission factor for a given vehicle class by the ratio of PM_{10} emission standards for each respective bin, as noted in Appendix Table D4.

f. Tier 1 LDT4 PM_{10} emissions assumed to be equivalent to Tier 2 bin 11 Class 2b Trucks.

g. Tier 1 LDT3 PM_{10} emissions computed by multiplying Tier 2 bin 11 LDT3 estimates (0.332 g/mi) and the ratio of LDT4 Tier 1-to-Tier 2 bin 11 estimates (0.418 / 0.398).

Appendix Table B1. Fuel Consumption-Dependent Emission Factors: Vehicle In-Use Emissions

Emission Factors (a)

Pollutant (vehicle standard)	Gasoline (g/gal)	Diesel (g/gal)	CNG (g/gal)	Notes
HC evap	*	0	0	(b)
SO_x	1.6	2.6	0.037	(c)
CH_4	4.4	0.47	45.6	(c)
N_2O	3.3	0.35	2.59	(c)
CO_2, g/gal	8200	9890	6250	(c)
CO_2, g/MJ	62.2	67.6	47.4	(d)

Notes:
Emission factors are derived from Delucchi (1997b), with spreadsheet references given in brackets [ ], except as otherwise noted.

a. Gasoline and CNG values are per gallon of gasoline equivalent ("gge," 125,000 Btu/gal); diesel values are per gallon of diesel (138,700 Btu/gal).
b. Evaporative hydrocarbon emissions are included in MOBILE6 emissions estimates. PZEV-certified models are post-corrected by subtracting the evaporative portion of gasoline SULEV vehicles as defined in DeCicco and Kliesch (2002), to reflect their "zero-evap" status. See text for more information.
c. Emissions estimates for CH_4, N_2O, and CO_2 were derived as follows: For gasoline, the values assume standard (not reformulated) gasoline [H: 48-62], and converted from g/mi to g/gal using Delucchi's model vehicle assumption of 29.5 MPG. The same procedure was followed for CNG vehicles. For diesel, since Delucchi does not estimate light-duty diesel emissions, we use his heavy-duty diesel g/mi estimates [H: 87-94] and convert them to g/gal using his modeled heavy-duty diesel vehicle fuel economy of 5.9 MPG. SO_x emission factors are based on the sulfur content of the fuel, as given in Delucchi (1997b).
d. CO_2 results are also shown in terms of a common energy unit, grams per megajoule (g/MJ). (1055 MJ = 1 MBtu).

Appendix Table B2. Fuel Consumption-Dependent Emission Factors: Upstream Emissions from Fuel Production, Distribution, and Vehicle Refueling

Pollutant	Gasoline (g/gal)	Diesel (g/gal)	CNG (g/gal)	Notes	Electricity (g/kWh) (i)
NMOG	6.1	1.6	1.0	(a)	0.010
CH_4	16.6	13.4	41.8	(b)	0.008
CO	6.3	5.1	3.8	(c)	0.095
N_2O	0.18	0.11	0.05	(d)	0.027
NO_x	8.5	6.4	6.9	(e)	2.031
SO_x	9.9	5.6	2.0	(f)	2.114
PM_{10}	1.0	0.7	0.5	(g)	0.070
CO_2	2450	1470	1190	(h)	647

Notes:
All values are from the Delucchi (1997b) GHG Model, with spreadsheet references given in brackets [ ]. Values given in g/MBtu (grams per million Btu) were converted to g/gge (grams per gallon of gasoline equivalent) using a higher heating value of 125,000 Btu/gal for gasoline.

a. NMOG: Table 10f [K: 224]
b. CH_4: Table 10b [K: 124]
c. CO: Table 10d [K: 184]
d. N_2O: Table 10c [K: 154]
e. NO_x: Table 10e [K: 214]
f. SO_x: Table 10g [K: 274]
g. PM_{10}: Table 10h [K: 304]
h. CO_2: Table 10a [K: 94]
i. National average generation mix, as detailed in Appendix Table B3 on the following page.

Appendix Table B3. Emission Factors for Electric Vehicle Recharging

Key Assumptions and Parameters:

	Fossil Fuel Resource and Technology					
	Coal	Oil	Natural Gas Boiler	Natural Gas Turbine	Electricity Nuclear	
Generation Mix (a)	56.3%	2.4%	7.2%	2.5%	23.4%	Average Net
Generation Efficiency	34.5%	34.5%	33.0%	33.0%		Efficiency:
Distribution Efficiency	92.0%	92.0%	92.0%	92.0%	92.0%	31.2%
Emission Rates (g/MBtu input)						
NMOG	1.36	2.30	0.64	1.92		
CH_4	0.91	0.85	0.13	10.89		
CO	11.34	15.15	18.10	49.90		
N_2O	4	2	2	2		
NO_x	306	126	155	124		
SO_x	341	197	0	0		
PM_{10}	11.30	5.60	0.14	1.90		
CO_2 (kg/MBtu)	95.3	75.0	53.5	53.5		

Resulting Estimates:

Emissions per unit of delivered power (g/MBtu)	Coal	Oil	Natural Gas Boiler	Natural Gas Turbine	National Average	Average g/kWh
NMOG	4.3	7.2	2.1	6.3	2.9	0.010
CH_4	2.9	2.7	0.4	35.9	2.6	0.009
CO	35.7	47.7	59.6	164	29.7	0.101
N_2O	12.6	6.3	6.6	6.6	7.9	0.027
NO_x	964	398	511	408	599	2.045
SO_x	1073	621	0.9	0.9	619	2.112
PM_{10}	35.6	17.6	0.5	6.3	20.7	0.070
CO_2 (kg/MBtu)	300	236	176	176	192	654

Nuclear Power Externality Cost		
Damage cost (¢/kWh)	0.61	(b)
Generation share	23.4%	
Cost (¢/kWh)	0.14	
Non-nuclear electricity cost (¢/kWh)	0.57	(c)
Overall external electricity cost (¢/kWh)	0.71	

Notes:

Source: Delucchi (1997b) GHG Model, Sheets D, J; DOE (2001) Electric Power Annual 2000, Vol. I, Table 6. Additional results calculated based on Form EIA-906 data available online at http://www.eia.doe.gov/cneaf/electricity/page/eia906u.html.

a. National average generation mix. The remainder is from renewable sources which are assumed to have zero or negligible emissions of the pollutants considered.

b. From Ottinger et al. (1991), "Environmental Costs of Electricity," p. 34 ("starting point" values), but counting only routine operations and decommissioning costs.

c. Derived from average g/kWh emission rates as given above, and damage costs as noted in Table 3.

Appendix Table C1. Emissions from Vehicle Manufacture and Assembly:

Vehicle Composition and the Energy Associated with Materials Production

			------------ Fraction of Production Energy by Fuel ------------					
					*fraction of oil**			
Material	Content Fraction	Production Energy (Btu/lb)	Coal	Oil	*residual*	*distillate*	Natural Gas	Electricity
Plain Carbon Steel	45.1%	13,315	0.59	0.06	*78.2%*	*21.8%*	0.23	0.13
Iron	14.6%	8,445	0.65	0.06	*78.2%*	*21.8%*	0.25	0.04
High Strength Steel	7.5%	20,876	0.59	0.06	*78.2%*	*21.8%*	0.23	0.13
Plastics, Composites	7.1%	61,433	0	0.28	*74.3%*	*25.7%*	0.70	0.02
Fluids, Lubricants	5.7%	0	0	0	*90.9%*	*9.1%*	0	0
Aluminum	5.0%	44,352	0.04	0.05	*50.0%*	*50.0%*	0.60	0.31
Rubber	4.3%	38,307	0.20	0.30	*78.0%*	*22.0%*	0.41	0.10
Glass	2.7%	8,408	0.02	0.18	*66.7%*	*33.3%*	0.75	0.05
Other (Lead)	2.6%	6,273	0.37	0.03	*50.0%*	*50.0%*	0.30	0.30
Copper	1.6%	46,303	0.56	0.19	*50.0%*	*50.0%*	0.13	0.11
Other Steel	1.5%	13,315	0.59	0.06	*78.2%*	*21.8%*	0.23	0.13
Stainless Steel	1.0%	22,220	0.63	0.06	*78.2%*	*21.8%*	0.20	0.11
Powdered metal	0.7%	3,926	0.03	0.38	*66.7%*	*33.3%*	0.29	0.29
Zinc die cast	0.6%	32,743	0.35	0	*50.0%*	*50.0%*	0.54	0.10
Sodium	0.0%	15,658	0.26	0.01	*63.6%*	*36.4%*	0	0.73
Titanium	0.0%	60,498	0.03	0.18	*50.0%*	*50.0%*	0.10	0.69
Sulfur	0.0%	443	0.60	0	*63.6%*	*36.4%*	0.30	0.10

Notes:
Source: DeLuchi (1991), Table P.4, for a typical light-duty gasoline vehicle.

* From Manufacturing Energy Consumption Survey (MECS), DOE (1991)

Appendix Table C2. Emissions from Vehicle Manufacture and Assembly:
Energy for Materials Production by Fuel (Btu per pound of vehicle)

Material	Coal	Residual Oil	Distillate Oil	Natural Gas	Electricity
Plain Carbon Steel	3,543	282	79	1,381	781
High Strength Steel	924	73	20	360	204
Stainless Steel	140	10	3	44	24
Other Steel	118	9	3	46	26
Iron	801	58	16	308	49
Plastics, Composites	0	907	314	3,053	87
Fluids, Lubricants	0	0	0	0	0
Rubber	329	385	109	675	165
Aluminum	89	55	55	1,331	687
Titanium	0	0	0	0	0
Glass	5	27	14	170	11
Copper	415	70	70	96	81
Zinc die cast	69	0	0	106	20
Powdered metal	1	7	3	8	8
Other (Lead)	60	2	2	49	49
Sodium	0	0	0	0	0
Sulfur	0	0	0	0	0
TOTAL	6,493	1,888	689	7,629	2,193
Electricity use in vehicle assembly (use of other fuels assumed negligible)					5,000
Total embodied electricity (Btu per pound of vehicle)					7,193

Appendix Table C3. Emissions from Vehicle Manufacture and Assembly:

Emission Factors and Summation of Embodied Emissions by Fuel

FUEL (units of energy content)	Energy Content (a)	Btu/lb. of vehicle (b)	NO_x	SO_2	PM_{10}
Coal (MBtu/ton)	28	6,493			
Emission factor, lb/ton (c)			14.4	34.2	
g/MBtu			233.28	554.04	
Embodied emissions, g/lb			1.5	3.60	
Residual oil (MBtu/gal)	0.147	1,888			
Emission factor, lb/1000 gal (c)			42	3.254	
g/MBtu			129.31	10.02	
Embodied emissions, g/lb			0.24	0.019	
Distillate oil (MBtu/gal)	0.138	689			
Emission factor, lb/1000 gal (c)			20	0.288	
g/MBtu			65.94	0.95	
Embodied emissions, g/lb			0.0456	0.0007	
Natural Gas (Btu/cf)	1,020	7,629			
Emission factor, lb/Mcf (c)			555	0.6	
g/MBtu			246.81	0.27	
Embodied emissions, g/lb			1.9	0.002	
Electricity (Btu/kWh)	3,412	7,193			
Emissions factor, g/MBtu (d)			740	1200	26
Embodied emissions, g/lb			5.3	8.6	0.2
Total Embodied Emissions					
grams per pound of vehicle			9.02	12.25	0.19
grams per kilogram of vehicle			19.84	26.95	0.41
adjusted for sulfur reductions (e)			19.84	24.26	0.41
adjusted for toxics release (f)			19.84	24.26	2.83
g/mi/kg, over a 100,000 mile vehicle lifetime			1.98E-004	2.43E-004	2.83E-005

Notes:

a. Babcock and Wilcox (1978); 1 MBtu = 10^6 Btu, cf = cubic foot.

b. From Appendix Table C2.

c. Electric Power Annual 1994 Vol. 2, Table A.3 (DOE 1995), assuming sulfur contents of 0.9% for bituminous coal, 2.0% for residual oil, and 0.2% for distillate.

d. Energy Innovations (1997).

e. The SO_2 estimate is reduced 10% to reflect improved SO_x controls from implementation of the 1990 Clean Air Act Amendments.

f. By adding 2.42 g of toxics per kg of vehicle mass, as derived from Keoleian et al. (1997) and described in the text.

Appendix Table D1. Intermediate Useful Life (50K mile) Exhaust Mass Emission Standards (g/mi): Carbon Monoxide (CO)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [g]
Tier 1	3.4	3.4	4.4	4.4	5.0	5.0
bin 11 [a]	5.0	5.0	5.0	5.0	5.0	5.0
bin 10 [a]	3.4	3.4	3.4	4.4	4.4	4.4
bin 9 [a]	3.4	3.4	3.4	3.4	3.4	3.4
bin 8 [a]	3.4	3.4	3.4	3.4	3.4	3.4
bin 7 [a]	3.4	3.4	3.4	3.4	3.4	3.4
bin 6 [a]	3.4	3.4	3.4	3.4	3.4	3.4
bin 5 [a]	3.4	3.4	3.4	3.4	3.4	3.4
bin 4 [b]	1.7	1.7	1.7	1.7	1.7	1.7
bin 3 [b]	1.7	1.7	1.7	1.7	1.7	1.7
bin 2 [b]	1.7	1.7	1.7	1.7	1.7	1.7
bin 1 [b]	0	0	0	0	0	0
LEV I [c]	3.4	3.4	4.4	4.4	5.0	5.5
ULEV I [c]	1.7	1.7	2.2	4.4	5.0	5.5
LEV II	3.4	3.4	3.4	3.4	3.4	6.4 [d]
ULEV II	1.7	1.7	1.7	1.7	1.7	6.4 [d]
SULEV II [e]	0.81	0.81	0.81	0.81	0.81	3.2 [d]
PZEV [f]	0.645	0.645	0.645	0.645	0.645	3.2 [d]
ZEV	0	0	0	0	0	0

Notes:

a. Federal Register (2000).

b. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for Tier 2 bins 1 through 4. Values shown are default "intermediate" values used in the MOBILE6 model, as stated in the T2CERT.D data file.

c. CARB (2002). Classification of vehicle types differ slightly between Federal and California LEV I/ULEV I regulations. Values shown for LDT3s, LDT4s, and Class 2b trucks reflect standards for MDVs (3,751-5,750 lbs. ALVW), MDVs (5,751-8,500 lbs. ALVW), and MDVs (8,501-10,000 lbs. ALVW), respectively.

d. CARB (2002). Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for vehicles greater than 8,501 lbs. GVW. Values shown are the 120,000 mile standard, and are included for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

e. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for SULEV II-certified vehicles. Values shown are estimated "intermediate" values, computed by the author as described in the text and Table 7.

f. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for PZEV-certified vehicles. Values shown are estimated "intermediate" values, computed by the author as described in the text. These values reflect 150,000 mile durability.

g. Emission standards of Class 2b trucks are included here for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

Appendix Table D2. Intermediate Useful Life (50K mile) Exhaust Mass Emission Standards (g/mi): Hydrocarbons (NMOG)

	LDV	LDT1	LDT2	LDT3	LDT4	2b[g]
Tier 1[h]	0.25	0.25	0.32	0.32	0.39	0.39
bin 11[a]	0.195	0.195	0.195	0.195	0.195	0.195
bin 10[a]	0.125	0.125	0.125	0.16	0.16	0.16
bin 9[a]	0.075	0.075	0.075	0.14	0.14	0.14
Bin 8[a]	0.100	0.100	0.100	0.125	0.125	0.125
Bin 7[a]	0.075	0.075	0.075	0.075	0.075	0.075
Bin 6[a]	0.075	0.075	0.075	0.075	0.075	0.075
Bin 5[a]	0.075	0.075	0.075	0.075	0.075	0.075
Bin 4[b]	0.051	0.051	0.051	0.051	0.051	0.051
Bin 3[b]	0.040	0.040	0.040	0.040	0.040	0.040
Bin 2[b]	0.007	0.007	0.007	0.007	0.007	0.007
Bin 1[b]	0	0	0	0	0	0
LEV I[c]	0.075	0.075	0.1	0.16	0.195	0.230
ULEV I[c]	0.04	0.04	0.05	0.10	0.117	0.138
LEV II	0.075	0.075	0.075	0.075	0.075	0.195[d]
ULEV II	0.04	0.04	0.04	0.04	0.04	0.143[d]
SULEV II[e]	0.007	0.007	0.007	0.007	0.007	0.100[d]
PZEV[f]	0.006	0.006	0.006	0.006	0.006	0.100[d]
ZEV	0	0	0	0	0	0

Notes:

a. Federal Register (2000).

b. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for Tier 2 bins 1 through 4. Values shown are default "intermediate" values used in the MOBILE6 model, as stated in the T2CERT.D data file.

c. CARB (2002). Classification of vehicle types differ slightly between Federal and California LEV I/ULEV I regulations. Values shown for LDT3s, LDT4s, and Class 2b trucks reflect standards for MDVs (3,751-5,750 lbs. ALVW), MDVs (5,751-8,500 lbs. ALVW), and MDVs (8,501-10,000 lbs. ALVW), respectively.

d. CARB (2002). Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for vehicles greater than 8,501 lbs. GVW. Values shown are the 120,000 mile standard, and are included for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

e. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for SULEV II-certified vehicles. Values shown are estimated "intermediate" values, computed by the author as described in the text and Table 7.

f. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for PZEV-certified vehicles. Values shown are estimated "intermediate" values, computed by the author as described in the text. These values reflect 150,000 mile durability.

g. Emission standards of Class 2b trucks are included here for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

h. Tier 1 standards apply to NMHC emissions for LDVs, LDT1s, and LDT2s, and THC emissions for LDT3s and larger.

Appendix Table D3. Intermediate Useful Life (50K mile) Exhaust Mass Emission Standards (g/mi): Nitrogen Oxides (NO_x)

	LDV	LDT1	LDT2	LDT3	LDT4	2b [g]
Tier 1	0.4	0.4	0.7	0.7	1.1	1.1
bin 11 [a]	0.6	0.6	0.6	0.6	0.6	0.6
bin 10 [a]	0.4	0.4	0.4	0.4	0.4	0.4
bin 9 [a]	0.2	0.2	0.2	0.2	0.2	0.2
bin 8 [a]	0.14	0.14	0.14	0.14	0.14	0.14
bin 7 [a]	0.11	0.11	0.11	0.11	0.11	0.11
bin 6 [a]	0.08	0.08	0.08	0.08	0.08	0.08
bin 5 [a]	0.05	0.05	0.05	0.05	0.05	0.05
bin 4 [b]	0.029	0.029	0.029	0.029	0.029	0.029
bin 3 [b]	0.021	0.021	0.021	0.021	0.021	0.021
bin 2 [b]	0.014	0.014	0.014	0.014	0.014	0.014
bin 1 [b]	0	0	0	0	0	0
LEV I [c]	0.2	0.2	0.4	0.4	0.6	0.7
ULEV I [c]	0.2	0.2	0.4	0.4	0.6	0.7
LEV II	0.05	0.05	0.05	0.05	0.05	0.2 [d]
ULEV II	0.05	0.05	0.05	0.05	0.05	0.2 [d]
SULEV II [e]	0.014	0.014	0.014	0.014	0.014	0.1 [d]
PZEV [f]	0.02	0.02	0.02	0.02	0.02	0.1 [d]
ZEV	0	0	0	0	0	0

Notes:

a. Federal Register (2000).

b. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for Tier 2 bins 1 through 4. Values shown are default "intermediate" values used in the MOBILE6 model, as stated in the T2CERT.D data file.

c. CARB (2002). Classification of vehicle types differ slightly between Federal and California LEV I/ULEV I regulations. Values shown for LDT3s, LDT4s, and Class 2b trucks reflect standards for MDVs (3,751-5,750 lbs. ALVW), MDVs (5,751-8,500 lbs. ALVW), and MDVs (8,501-10,000 lbs. ALVW), respectively.

d. CARB (2002). Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for vehicles greater than 8,501 lbs. GVW. Values shown are the 120,000 mile standard, and are included for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

e. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for SULEV II-certified vehicles. Values shown are estimated "intermediate" values, computed by the author as described in the text and Table 7.

f. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for PZEV-certified vehicles. Values shown are estimated "intermediate" values, computed by the author as described in the text. These values reflect 150,000 mile durability.

g. Emission standards of Class 2b trucks are included here for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

Appendix Table D4. Intermediate Useful Life (50K mile) Exhaust Mass Emission Standards (g/mi): Particulate Matter (PM_{10})

	LDV	LDT1	LDT2	LDT3	LDT4	2b [f]
Tier 1 [g]	0.08	0.08	0.08	0.10	0.12	0.12
bin 11 [a]	0.12	0.12	0.12	0.12	0.12	0.12
bin 10 [a]	0.08	0.08	0.08	0.08	0.08	0.08
bin 9 [a]	0.06	0.06	0.06	0.06	0.06	0.06
bin 8 [a]	0.02	0.02	0.02	0.02	0.02	0.02
bin 7 [a]	0.02	0.02	0.02	0.02	0.02	0.02
bin 6 [a]	0.01	0.01	0.01	0.01	0.01	0.01
bin 5 [a]	0.01	0.01	0.01	0.01	0.01	0.01
bin 4 [b]	0.01	0.01	0.01	0.01	0.01	0.01
bin 3 [b]	0.01	0.01	0.01	0.01	0.01	0.01
bin 2 [b]	0.01	0.01	0.01	0.01	0.01	0.01
bin 1 [b]	0	0	0	0	0	0
LEV I [c]	0.08	0.08	0.10	0.10	0.12	0.12
ULEV I [c]	0.04	0.04	0.05	0.05	0.06	0.06
LEV II [e]	0.01	0.01	0.01	0.01	0.01	0.12 [d]
ULEV II [e]	0.01	0.01	0.01	0.01	0.01	0.06 [d]
SULEV II [e]	0.01	0.01	0.01	0.01	0.01	0.06 [d]
PZEV [e]	0.01	0.01	0.01	0.01	0.01	0.06 [d]
ZEV	0	0	0	0	0	0

Notes:

a. Federal Register (2000). See "Particulate Emissions" in text for real-world estimation of this pollutant.

b. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for Tier 2 bins 1 through 4. Values shown are the 120,000 mile standard, and are included for informational purposes only; see "Particulate Emissions" for real-world estimation of this pollutant.

c. CARB (2002). Intermediate useful life (50,000 mile) exhaust mass PM_{10} emissions standards do not exist for LEV I- and ULEV I-certified vehicles. Values shown are the 100,000 mile standard for LDT2s and 120,000 mile standards for LDT3s and larger. Classification of vehicle types differ slightly between Federal and California LEV I/ULEV I regulations. Values shown for LDT3s, LDT4s, and Class 2b trucks reflect standards for MDVs (3,751-5,750 lbs. ALVW), MDVs (5,751-8,500 lbs. ALVW), and MDVs (8,501-10,000 lbs. ALVW), respectively.

d. CARB (2002). Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for vehicles greater than 8,501 lbs. GVW. Values shown are the 120,000 mile standard, and are included for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

e. Intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for LEV II type-certified vehicles. Values shown are the 120,000 mile standard, and are included for informational purposes only; see "Particulate Emissions" for real-world estimation of this pollutant.

f. Emission standards of Class 2b trucks are included here for informational purposes only; see "Methodology for Class 2b Trucks" for the scoring approach of these vehicles.

g. A PM_{10} standard is not specified for gasoline vehicles; the diesel PM_{10} standard is shown. Tier 1 intermediate useful life (50,000 mile) exhaust mass emissions standards do not exist for LDT3s, LDT4s, and Class 2b trucks. Values shown for these classes are the 120,000 mile standard.

Appendix E

VEHICLE INCLUSION AND CLASSIFICATION

The foundation for inclusion and classification of vehicles in *ACEEE's Green Book*® is the EPA database of models certified as meeting the applicable regulatory standards in the United States in a given model year. ACEEE provides ratings only for vehicles offered for general sale by established automakers having a mass-production track record. Concept vehicles, prototypes, and pre-market test products not yet offered for general sale will not be listed; neither will aftermarket devices or conversion vehicles, or other vehicles not certified under U.S. safety and emissions regulatory programs. Makes and models not included in the applicable government certification databases are not eligible for inclusion in *ACEEE's Green Book*®. Although ACEEE will attempt to rate all vehicles eligible as noted here, ACEEE cannot assure the listing of all vehicles that might be deemed eligible.

Classification is important to the presentation of environmental rating information, since the market is segmented into classes and consumers often compare a given model with others in its class. Yet no classification scheme is perfect. Class boundaries based on well-defined dimensions can result in seemingly arbitrary class distinctions among vehicles that fall near the boundaries. The market is, moreover, continuously evolving. A notable class that is important today, minivans, did not even exist 25 years ago. One of today's most popular segments, luxury sport utility vehicles, is a far cry from the utilitarian jeeps and work vehicles of the past. The lines between station wagons, minivans, and sport utilities can be quite fuzzy. These segments have been in flux, with emerging "crossover vehicles" such as Chrysler's Pacifica and Subaru's Forester (the latter classified by EPA as a Special Purpose Vehicle but being similar to a Midsize Wagon with 4-wheel drive). Because crossover vehicles don't fit exactly into the designated *Green Book* vehicle classes, they have been listed in the class to which they are most related, or that best reflects their position in the market.

The starting point for our classification scheme is the one used by EPA in its databases and as used in the annual *Fuel Economy Guide* (DOE 2003). This publication is generally released in October of the calendar year proceeding the nominal model year; for example, DOE (2003) is the *Model Year 2004 Fuel Economy Guide.* It defines car classes based on interior volume, with a body style distinction separating wagons from coupes and sedans, and it defines light truck classes based on body styles.

Passenger Cars

For passenger cars, we use a slight aggregation of the EPA size classes. The EPA classification is based on the sum of passenger and luggage volume, with the specific volume cut-off for each class as specified in the *Fuel Economy Guide.* We combine Minicompacts and Subcompacts into a single class which we term Subcompact Cars. We combine Midsize Station Wagons and Large Station Wagons into a single class, which we term Midsize Wagons. The resulting classes are: Two Seaters, Subcompact Cars, Compact Cars, Midsize Cars, Large Cars, Small Wagons, and Midsize Wagons.

Light-Duty Trucks

For light trucks, we significantly modify the EPA size classes, disaggregating vehicles further than is done in the *Fuel Economy Guide.* Wishing to better represent the characteristics of the vehicles from a market perspective, we adopt a classification similar to those in consumer guides such as *The Ultimate Car Book* (Gillis 1999) and *Consumer Reports* (2003).

Pickups. EPA classes divide pickups into Compact and Standard based on Gross Vehicle Weight Ratings. These definitions lead to trucks such as the Ford Ranger and Ford F-150 being classified together. To separate these clearly different market segments but still maintain a simple rating system, we classify pickups by their wheelbase (a specification routinely reported by manufacturers). We use the roughly bimodal distribution of pickups by wheelbase to classify pickups as either Compact (Chevrolet Colorado, Dodge Dakota, Ford Ranger) or Standard (Chevrolet Silverado, Dodge Ram, Ford F-150). In addition, we do not classify four-wheel drive (4WD) and two-wheel drive (2WD) pickups separately as in the EPA classification.

Vans. The *Fuel Economy Guide* divides vans into Passenger and Cargo categories, without clear distinctions. In this case, we largely abandon the EPA classifications. We again use wheelbase as a determinant and use the roughly bimodal distribution to classify vans as either Minivans or Large Vans. This classification is also consistent with the consumer guides. The only model that does not fit clearly into either category is the Chevrolet Astro and GMC Safari twin. Based on *The Ultimate Car Book* and *Consumer Reports*, we classify it as a Minivan.

Sport Utility Vehicles. We use a SUV classification scheme representative of market segments, distinguishing, for example, between vehicles such as the Chevrolet Tracker and the GMC Yukon. Again, wheelbase provides a good determinant. The three-class division (Compact, Midsize, and Large) used in *The Ultimate Car Book* has been well suited for classifying sport utility vehicles. Examples of Compact SUVs include the Chevrolet Tracker, Ford Escape, and Toyota RAV4. Midsize SUVs include the Chevrolet Blazer and Jeep Grand Cherokee. Large SUVs, typically built on Standard Pickup frames, include the Chevrolet Suburban and Ford Expedition. We avoid a classification distinction between 4WD and 2WD, listing these drivetrain variants together within a given utility vehicle size class.

Distributions of EDX by Vehicle Class

The distributions of EDX for all cars, all light trucks, and the overall model year 2004 light-duty fleet is given in Figure 2. Appendix Table E1 identifies the EDX cutpoints used to determine the symbolic within-class rankings assigned to vehicles in *ACEEE's Green Book*®, based on the criteria shown in Table 6.

Appendix Table E1. Cutpoints Used to Determine Class Rankings for Model Year 2004 Vehicles

	Class Ranking Upper Limits (EDX, ¢/mi)[a]				
Vehicle Class	Superior	Above Average	Average	Below Average	Inferior
	✓	▲	○	▽	✖
Percentile Guideline	95% +	80%–95%	35%–80%	15%–35%	0–15%
Two Seaters	1.17	2.11	2.47	3.33	>3.33
Subcompact Cars	1.77	2.02	2.28	2.55	>2.55
Compact Cars	1.56	1.79	2.12	2.30	>2.30
Midsize Cars	1.75	2.01	2.27	2.45	>2.45
Large Cars	2.00	2.14	2.49	2.66	>2.66
Small Wagons	1.74	1.82	2.16	2.39	>2.39
Midsize Wagons	1.80	1.98	2.31	2.45	>2.45
Compact Pickups	2.16	2.37	2.72	2.90	>2.90
Standard Pickups	2.44	2.89	3.19	3.38	>3.38
Compact SUVs	2.03	2.12	2.38	2.48	>2.48
Midsize SUVs	2.31	2.52	2.90	3.12	>3.12
Large SUVs	2.44	3.22	3.51	3.76	>3.76
Minivans	2.27	2.38	2.71	2.95	>2.95
Large Vans	2.44	3.15	3.35	3.47	>3.47

Notes:

a. A vehicle is assigned a given class ranking if its environmental damage index (EDX) is less than the cutpoint for the ranking and, for a Superior ranking, if its Green Score is no less than the overall 2004 average of 27 (corresponding to the MY2004 combined car-truck average EDX of 2.44¢/mi).

Appendix F

SUMMARY OF REVISIONS FOR 2004

A number of modifications to our environmental rating methodology were made between model years 2003 and 2004. Although the life-cycle assessment principles underlying the *ACEEE's Green Book®* methodology have largely remained constant between these years, the MY2004 introduction of Tier 2 and LEV II emission standards has necessitated a substantial revision to the approaches used in determining vehicles' real world emission factors. Additionally, the methodology for model year 2004 was modified to incorporate the framework of the new standards, while maintaining the overall assessment approach used in past editions of the *Green Book.*

Unlike the framework of Tier 1 and LEV I standards, Tier 2 and LEV II standards are specified independent of vehicle class and fuel type. However, the real world emissions of a range of vehicles meeting a given Tier 2 or LEV II standard are not necessarily equal. Consequently, an approach for modeling lifetime average emissions was developed to operate under the framework of the new tailpipe standards, while still acknowledging the variation of emissions across vehicle class and operating fuel.

Previous years' computations included the modeling of HC and NO_x emissions estimates with software developed at EPA (Koupal 2001). This software reflected fuel effects and other in-use effects for each vehicle class and standard. While the model, which we refer to as "FER" in DeCicco and Kliesch (2002), was developed as a working analysis tool for the preparation of Tier 2 and sulfur standards, its assumptions were consistent with draft assumptions for MOBILE6 which, at the time, had not been finalized.

Given the recent finalization of MOBILE6 – a software application developed by EPA to provide estimates of current and future motor vehicle emissions – the MOBILE6 model was used as the foundation of a new set of emission factors for model year 2004 vehicles. In a number of cases, previous years' scaling approaches using (for example) ratios of emission standards were abandoned in favor of more detailed computations using the MOBILE6 model. And while there are some notable differences in the numeric values of last year's and this year's emission factors, our mapping of a vehicle's composite environmental score (the *environmental damage index*, or *EDX*) to a *Green Score* that resides on a [0–100] scale (and which is not tied to a particular model year) accommodates updates to the methodology while maintaining a consistent scale for consumers. Compared to model year 2003, key parameter changes and other items of note include the following:

- Use of MOBILE6.2 to derive HC, CO, and NO_x lifetime average emissions estimates
- Incorporation of VMT and survival rates (by age) in estimating lifetime average emissions levels
- Updating of particulate matter (PM) emissions estimates
- Updating of diesel vehicle emissions estimates
- Updating of compressed natural gas (CNG) vehicle emissions estimates
- Removal of the weight adjustment for hybrid-electric vehicles

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