Rating the Environmental Impacts of Motor Vehicles: *ACEEE's Green Book™* Methodology, 2001 Edition

John DeCicco and James Kliesch

May 2001

American Council for an Energy-Efficient Economy
1001 Connecticut Avenue NW, Suite 801, Washington, DC 20036

DeCicco, John, and James Kliesch
Rating the Environmental Impacts of Motor Vehicles:
***ACEEE's Green Book™* Methodology, 2001 Edition**
Washington, DC: American Council for an Energy-Efficient Economy, May 2001.
Transportation Efficiency Program, Report T011

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 *ACEEE's Green Book™: The Environmental Guide to Cars and Trucks – Model Year 2001.*

To order additional copies of this report or copies of *ACEEE's Green Book™*, please contact:

ACEEE Publications
1001 Connecticut Avenue NW, Suite 801
Washington, DC 20036-5525

Phone: (202) 429-0063, Fax: (202) 429-0193
E-mail: pubs@aceee.org
World Wide Web: www.aceee.org or www.GreenerCars.com

The 1998, 1999, and 2000 editions of *ACEEE's Green Book™* 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.

Rating the Environmental Impacts of Motor Vehicles: *ACEEE's Green Book*™ Methodology, 2001 Edition

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 booklet 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 2001 model year, 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.

Table of Contents

List of Tables

List of Figures

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, can help guide fleet programs and other market-creation initiatives, and can assist automakers' efforts to market "greener" products.

To address these informational needs, since 1998 ACEEE has published an annual, consumer-oriented booklet, 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 *ACEEE's Green Book™: The Environmental Guide to Cars and Trucks – Model Year 2001* (DeCicco and Kliesch 2001). It summarizes the application of the methodology to the 2001 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 carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM). (To date, PM standards are 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 2 to 4 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. For the 2001 model year, tailpipe emissions estimates for gasoline and diesel vehicles were adopted based on information developed for EPA's forthcoming MOBILE 6 model (EPA 1999a; Koupal 1999). 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.

Subsequent to the finalization of our MY2001 Methodology in early fall, 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 *ACEEE's Green Book* ratings are derived from the same source data as EPA's ratings, there are a number of technical differences. Our approach is lifecycle-based; EPA's is based separately on tailpipe emissions and fuel economy, which are dominant aspects of a vehicles lifecycle 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 CNG ULEV to a gasoline ULEV.) There are a number of other technical differences, such as our inclusion of heavier light trucks (8,500–10,000 lb GVW), as well as a different approach to presentation of results. Nevertheless, given that EPA's approach does capture the dominant impacts, we do not expect large differences in how most vehicles compare overall, although our system does more finely discriminate among vehicles. We will monitor the development of EPA's system and consider incorporating information from it in future editions of the *Green Book.*

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 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:

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

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:

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

Here, 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).

CHARACTERIZATION OF IMPACTS

Given the data availability as noted above, the above relation 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 carbon monoxide (CO), non-methane organic gases, hydrocarbons (HC), nitrogen oxides (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 non-methane organic gases (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 sulfur dioxide (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 the principal standards in effect in 2001. The detailed assumptions for estimated in-use emissions for each emissions standard are presented in a multi-part table (Table A1) in the appendix.

Supplemental Federal Test Procedure. The Supplemental Federal Test Procedure (SFTP) was introduced in Model Year 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). Incorporation of the SFTP in the *Green Book* methodology necessitated modest reductions of our in-use tailpipe emissions factors for gasoline vehicles. Although the SFTP program follows a legislated phase-in schedule, it is impractical for *ACEEE's Green Book*™ to identify specifically which vehicles are SFTP-compliant and which are not. Therefore, all MY2001 vehicles are treated as SFTP-compliant. The EPA emissions modeling tool we currently use (Koupal 1999) incorporates SFTP functionality, reflecting reductions of HC and NO_x in-use emissions expected by control improvements motivated by the SFTP.

SFTP-related reductions in CO emissions estimates were determined in consultation with members of EPA's MOBILE 6 modeling staff (Koupal 2000). Using preliminary MOBILE 6-based adjustment estimates of both Tier 1 off-cycle benefits and class-specific LEV off-cycle benefits (used here on LEVs and ULEVs), MY2000 off-cycle CO estimates were adjusted to yield new, MY2001 SFTP-based off-cycle estimates. The adjustment factors account for both control improvement-related emissions reductions, and a modest CO increase due to air conditioning loading, as noted in Appendix Table A1.

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 acknowledging the large uncertainty regarding light duty diesel in-use emissions, the absence of data suggests caution. Therefore, we leave all diesel emissions factors unchanged from our MY2000 estimates, as described below under *Diesel Emissions*.

Addressing Gasoline Characteristics. The two most significant gasoline characteristics impacting tailpipe emissions are gasoline sulfur content and the use of reformulated gasoline.

Sulfur Level. The characterization of NO_x emissions in terms of fuel sulfur is among the more critical judgements made for our methodology, since NO_x is weighted much more heavily than HC and CO in determining a vehicle's EDX (see Table 4 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 (LEVs, etc.) 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, LEVs 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 a national average of 30 ppm by 2006 (Federal Register 2000). Since we characterize emissions over the entire vehicle lifetime, it is appropriate to evaluate vehicles at some expected average sulfur level. Also, although a number of LEVs are available nationwide, they are only required in states adopting the California emissions control program (CA, MA, NY, VT, and ME in MY2001). These states have lower sulfur fuel than is typically available nationwide. Thus, we characterize LEVs at the expected lifetime sulfur level in LEV-mandated states, and we characterize Tier 1 vehicles at an expected lifetime average sulfur level in the remaining states.

In order to determine lifetime averages for the states adopting the California emissions control program as well as the remaining states, we first calculate a national average fuel sulfur level over the vehicle lifetime. Estimated sulfur projections were determined using 1998 AAMA survey data, and average annual miles per vehicle by age (ORNL 1997). Sulfur phase-in assumptions were made in line with EPA's Tier 2 modeling (EPA 1999b). For each year, we multiply the sulfur level by the fraction of lifetime vehicle miles driven that year. When summing over an assumed 120,000-mile vehicle lifetime, this approach yields a national average fuel sulfur level of 70 ppm to be experienced by MY2001 vehicles.

Estimation of the average sulfur level for the five states requiring LEVs necessitated the use of region-specific sulfur estimates (AAMA 1997). We found a lifetime average for each of these five regions, and weighted them by state VMT (DOT 1998). In MY2000, LEV-mandated states account for 18.4% of the national VMT share, while the remaining states account for 81.6%. Based on these statistics, we estimate a LEV-state composite sulfur level of 30 ppm, and a composite sulfur level of 80 ppm for the remaining states.

Reformulated Gasoline. This year, we again modeled HC and NO_x emissions estimates with software developed at EPA. The spreadsheet model created at EPA (Koupal 1999) has proved to be a useful tool for estimating these emissions, reflecting fuel effects and the other in-use effects for each vehicle class and standard. This model, which we refer to here as "FER," is a working analysis tool used in the preparation of Tier 2 and sulfur standards. Its assumptions are intended to be consistent with draft MOBILE 6, with the caveat that the MOBILE 6 methodology was not final at the time we had to finalize our estimation procedures for MY2001.

The FER model, in calculating HC and NO_x tailpipe emissions, allows the user to model the use of either industry average or reformulated gasoline (RFG). RFG 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 weight RFG and conventional gasoline tailpipe emissions by this percentage. We calculate both RFG and conventional gasoline emission rates, and then weight these values to approximate national consumption levels of RFG and conventional gasoline.

HC and NO_x Emissions Characterization. FER accepts the following input variables: vehicle weight class, emissions standard, Inspection and Maintenance (I/M) requirements, sulfur content, RFG/conventional gasoline, and Supplemental Federal Test Procedure (SFTP) compliance. In order to estimate emissions rates for MY2001 vehicles, we selected the following input parameters (see also *Sulfur Level,* above):

I/M:	No
Sulfur:	30 ppm, lifetime avg., for California-certified vehicles
	80 ppm, lifetime avg., for Federal (Tier 1) vehicles
Fuel:	RFG, Conventional (weighted average)
SFTP:	Yes

When running FER, vehicle classes and standards are selected to determine emission rates for the various vehicle configurations. While the model does not explicitly allow for an Ultra-Low Emission Vehicle (ULEV) input standard, we simulate ULEV standards by adjusting one of the model's parameters (the 50K-mile standard). We judge that an OBD-only scenario best characterizes national average performance, so no I/M was selected. SFTP was included in our analysis to account for its introduction in MY2001 (see *Supplemental Federal Test Procedure* above).

As in EPA's models, emission rates for each pollutant are calculated as a function of a zero-mile rate, two deterioration rates, and a "flex" point, or point of inflection between the two deterioration rates.

$$e(m) = \begin{cases} e_0 + d_1 m & 0 \le m < m_1 \\ e_0 + d_1 m_1 & m = m_1 \\ e_1 + d_2(m - m_1) & m > m_1 \end{cases} \qquad (1)$$

where

$e(m)$ = vehicle emission rate as a function of mileage and deterioration rates

e_0 = zero-mile emission rate (g/mi)

e_1 = emission rate at flex point (g/mi)
d_1 = deterioration rate 1 (g/mi per 10,000 mi)
d_2 = deterioration rate 2 (g/mi per 10,000 mi)
m_1 = mileage at flex point (10,000 mi)

Integrating this relationship enables us to determine a lifetime average emission rate, $\bar{e}$, assuming an average vehicle lifetime (m_2) of 120,000 miles for all vehicles.

$$\bar{e} = e_0 + \frac{1}{2}(d_2 m_2) - (d_2 - d_1)(1 - \frac{m_1}{2m_2})m_1 \qquad (2)$$

This function is used to estimate the lifetime average emission rate for all three species (CO, HC, and NO_x), for each standard (Tier 1, LEV, etc.), and for each vehicle class (LDV, LDT1-4, etc.) as applicable.

The relevant output parameters of the FER model are the emission rate coefficients needed for Equation (2) above: e_0, d_1, d_2, and m_1. From these coefficients, we determine lifetime average emission rates.

CO Emissions Characterization. FTP-based, base CO emission rates for Tier 1, LEV, and ULEV cars and trucks are provided by EPA (1999a). While this report contained relevant information for use in our ratings (specifically, the "OBD-only" case) in chart form, it did not contain the numeric data from which the charts were based. EPA personnel provided us with the data (including zero-mile levels), and we performed further analysis to estimate deterioration rates from which our lifetime averages are calculated. Examining the data, we were able to determine the point of inflection (flex) between two deterioration rates. Specifically,

$$d_1 = \frac{(e_1 - e_0)}{m_1}$$

and $$d_2 = \frac{(e_2 - e_1)}{(m_2 - m_1)}$$

where e_2 = emissions rate at data endpoint (g/mi)
m_2 = mileage at data endpoint (10,000 mi)

Lifetime average CO emission rates were then calculated using Equation (2). This estimation addressed emissions in four categories:

(1) Tier 1 and LEV LDVs and LDT1s
(2) Tier 1 and LEV LDT2s and LDT3s
(3) ULEV LDVs and LDT1s

(4) ULEV LDT2s and LDT3s

The unavailability of LDT4 CO emission rates necessitated that we devise an approximate value based on available data. To determine CO emission rates for LDT4s, we multiplied the ratio of the LDT4 and LDT3 CO emission standards (5.0 g/mi:4.4 g/mi) by the LDT3 emission rate. Since LDT3 and 4 emission standards are the same for Tier 1, LEV, and ULEVs, the same ratio (5.0/4.4) was used to determine LDT4 emission rates for each of these three emission categories.

Our determination of gasoline vehicle CO emission rates accounts for FTP (on-cycle) only. Therefore, an off-cycle correction factor that accounts for SFTP-based adjustments is added to the base emission rates. As stated earlier, these adjustment factors account for control improvement-related emissions reductions, as well as a modest CO increase due to air conditioning loading. Assumptions behind the CO off-cycle emissions adjustments are documented in Appendix Table A1; results are located in Tables A1a-d.

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 PART model, generally characterize PM_{10} (particulates up to 10 microns in diameter), 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 this point, PM emissions characterizations for motor vehicles remain highly uncertain and remain based on PM_{10} data.

Delucchi (1997b) estimates Tier 1 gasoline light duty vehicle (LDV) PM_{10} emissions of 0.042 g/mi, based on a review of previously reported measurements. But recent data on vehicles with 3-way catalysts reveals significantly lower PM_{10} emission rates (Durbin et al. 1997, Mark and Morey 1999). Nevertheless, such mass-based data is likely to underestimate the impacts of ultrafine PM, for which real-world data are not available. Therefore, we assumed an emissions rate for LDVs that is one-half that of the Delucchi (1997b) estimate, yielding a value of 0.02 g/mi for Tier 1 LDVs. PM_{10} emissions rates for light duty trucks (LDTs) and for California certified vehicles are scaled from this Tier 1 LDV rate as shown in Tables A1b-d.

Diesel Emissions. Real-world data on diesel tailpipe emissions are even more limited than for gasoline vehicles. The SFTP final rule (Federal Register 1996) contains data on diesel NO_x emissions from a few manufacturers' test results for passenger cars only. The SFTP regulates off-cycle emissions by requiring the testing of vehicles over the US06 driving cycle, which includes more episodes of high power driving than the standard FTP cycle. To divide these emissions into on-cycle and off-cycle components, we adopt the SFTP estimates of 28% off-cycle and 72% on-cycle.

The MOBILE 6 emission factors under development for light duty diesel vehicles were reflected in EPA (1999c). From this document and conversations with EPA staff, we learned that basic zero-mile rates and deterioration rates will be unchanged from MOBILE 5 and that these rates do not include off-cycle (non-FTP) driving patterns. Moreover, MOBILE 5 does not have separate estimates for each of the four light-duty truck classes, instead giving a single rate labeled "Light Duty Diesel Trucks." MOBILE 6 light-duty diesel off-cycle emissions factors were not finalized in time for our MY2001 Methodology, therefore we retain the estimation procedure we developed in previous years.

We modify EPA (1999c) diesel estimates by adding an off-cycle component and separately estimating emissions for each of the four light-duty truck weight classes. As stated above, we use data reported in the SFTP Final Rule (Federal Register 1996) to incorporate the effects of off-cycle emissions. Zero-mile level and deterioration rate estimates were used to interpolate a 60,000-mile emissions estimate (the midpoint of a 120,000-mile vehicle lifetime), and then broken into on- and off-cycle components using the 72%/28% on-cycle/off-cycle apportionment used in the SFTP Final Rule. For example, since the 60,000-mile LDV on-cycle NO_x estimate of 1.05 g/mi comprises 72% of combined on- and off-cycle emissions, a resulting 0.41 g/mi accounts for the off-cycle portion of total emissions.

To arrive at estimates for each of the LDT weight classes, we assume that the EPA (1999c) estimates apply to LDT2s (the most common weight class). For the remaining LDT weight classes, we scale the on-cycle portion of emissions by the ratio of each weight class's emission standard to the LDT2 standard. Diesel emissions estimates are located in Table A1f.

Compressed Natural Gas Vehicles. A set of emission factors was also developed for compressed natural gas (CNG) vehicles. Bi-fuel vehicles are not specifically covered in *ACEEE's Green Book™*. Automakers' dedicated CNG vehicles all meet California's ULEV or SULEV emission standards. Estimates of real-world tailpipe emissions for the vehicles are drawn from both the updated GREET model (Wang 1999) and Delucchi (1997b), as detailed in Tables A1g-h. These 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 TLEV-certified Vehicles. The FER model (Koupal 1999) does not have estimates for TLEV emissions. For NO_x and CO, TLEV emissions standards are the same as Tier 1 standards. For CO, we use the Tier 1 estimates. For NO_x, we follow the same estimation procedure used for Tier 1 vehicles, but evaluate emissions at the lower, LEV-state sulfur level of 40 ppm. For HC, TLEV standards are lower than Tier 1. In the MY1999 methodology, TLEV HC emissions were estimated by scaling the on-cycle and degradation portions of the total emissions by the ratio of Tier 1 to TLEV standards. This apportionment was not available in draft MOBILE 6 documents for the MY2000 methodology, and a TLEV HC emission level midway between the Tier 1 and LEV rate was assumed. Our framework for analyzing TLEV vehicles remained the same for MY2001. TLEV emissions estimates are shown in Appendix Table A1b.

Methodology for Heavier Light Trucks

Vehicles between 8,500 lb. GVW and 10,000 lb. GVW (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. We refer to these vehicles, having a GVW greater than 8,500 lb. and up to 10,000 lb., as "Heavier Light Trucks" (HLTs). Inclusion of these vehicles in our ratings required the development of a procedure for estimating their lifetime average real-world emissions in a manner consistent with vehicles subject to light-duty regulations.

Since HLTs are exempt from Corporate Average Fuel Economy (CAFE) standards, EPA does not collect fuel economy data. We mailed letters to manufacturers of HLTs requesting fuel economy data and related specifications for their HLTs. No automakers provided us with such data. Therefore, we developed a procedure for estimating HLT fuel economy and emissions by scaling from an LDT model of which the HLT 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 not be 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 HLT fuel economy, we scale from the corresponding vehicle's LDT fuel economy as described below. This scaling was done using mass sensitivity coefficients derived from the An and Ross (1993) fuel economy model. We used a coefficient of -0.27 for city fuel economy and -0.23 for highway. Given the small mass differences, a linear approximation was used; in the city cycle case, for example:

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

where "m" designates mass (vehicle curb weight), MPG is fuel economy, and subscripts refer to (1) the base LDT for which fuel economy is known and (2) the HLT variant for which fuel economy needs to be estimated. These coefficients assume that other key vehicle parameters are constant; in particular, engine displacement is constant because we address only HLTs 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 an HLT 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 HLT fuel economy data from the standard LDV/LDT test cycles.

Emissions Estimation. To estimate tailpipe emissions, we assumed that HLT emission characteristics 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 both HLT 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 HLT vehicle specifications yielded an average HLT's 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 HLT ITW to average LDT4 ITW. These load-scaling factors are shown in Table A1, and the resulting emission factors are shown in Table A1a for gasoline Tier 1 vehicles, Table A1c for gasoline LEV vehicles, and Table A1f for diesels. Before settling on an approach, we investigated approaches similar to our method for LDTs of scaling up from LDV emission rates based on the ratio of HLT to LDV standards. HLT standards are so lax, however, that this approach produced unreasonably high results, given that the vehicles carry ECS technology similar to that of LDVs.

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. For consistency with other aspects of our methodology, rather than grams/test levels, we use evaporative emissions factors in grams/gallon (g/gal), derived from Delucchi (1997b). Federal and California-certified vehicles meet the same gram/test standard. However, the California test procedure is more stringent, so we adjust the estimates downward for California-certified vehicles based on Newell (1997). 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. Evaporative hydrocarbon emissions in gasoline SULEV vehicles are 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 Table A2a.

To estimate evaporative emissions for HLTs, we scaled the LDV rates (see below) by the ratio of HLT to LDV evaporative standards (3.0/2.0 g/test). This method is similar to the one used by EPA in the MOBILE 5a model (EPA 1996) and is based on the fact that evaporative emissions test procedures are the same and that control equipment is largely the same for both HLTs and LDTs. See Table A2a for details.

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 g/mi basis, which we convert to a g/gal 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 g/mi estimates and convert them to g/gal 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 Table A2a.

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 g/MBtu (grams per 10^6 Btu) and those relevant to our analysis are detailed in Table A2b. We then computed g/mi estimates from each vehicle's estimated in-use fuel economy, which is estimated as described below.

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 (kWh/mi) data supplied directly by automakers for their electric vehicles; we list these data as an efficiency rating (mi/kWh) 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 (1997) estimates for a national average power generation mix as detailed in Table A2c. 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.

To facilitate comparisons among fuels, direct CO_2 emissions and full fuel-cycle CO_2-equivalent GHG emissions are summarized by fuel in Table A4. For gasoline, for example, full cycle accounting results in greenhouse impacts roughly 60% higher than the CO_2 directly released during combustion.

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 Table A3. The resulting emission factors in g/mi per kg of vehicle mass are shown here 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 kg 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 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 lifecycle 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 MY2001 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)

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 (EDX) 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 – $2500 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 10 for reducing the damage cost of pollutants from electric utilities relative to those from vehicles. We selected a reduction factor of 5 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 current California standards, which are strongly oriented to HC reduction and cut NO_x by only a factor of two from the Federal level. Our valuations would reflect a significantly greater benefit for the LEV II standards, which would cut nominal NO_x emissions by a factor of eight from the current Federal level (CARB 1997).

Since the average U.S. electricity generation mix includes a significant share (19%) 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 et al. (1991, 34) provide 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 Table A2c, prorating this estimate by the 18.6% share of nuclear power in the mix adds 0.11¢/kWh (about 16%) to the overall external cost of electricity, which we estimate at 0.68¢/kWh. This value is used to calculate the environmental damage from electric vehicle use and from electricity used in vehicle manufacturing.

Damage cost estimates for toxics are not readily available. The 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 for plantations in Central America to \$200/T_C for plantations in North America (Ottinger 1991, 165-185; "T_C" refers to metric tons expressed on a carbon-mass basis). 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 commits 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 2001 and carried out the rating analysis for each configuration of every make and model (1,025 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 2001 EDX results range from 0.97¢/mi (a SULEV-certified CNG car and a small hybrid-electric vehicle) to 4.12¢/mi (a large, 4-wheel drive pickup truck). The median is 2.29¢/mi and one-half of the models fall between 2.02 and 2.79¢/mi.

Tables 4 and 5 detail the EDX calculations for an average model year 2001 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 (¢/mi). For the average car, the three criteria emissions components are 0.40¢/mi (46%) at the vehicle, 0.25¢/mi (28%) from the fuel cycle, and 0.23¢/mi (26%) embodied, summing to 0.88¢/mi (100% of life-cycle criteria emissions impact as calculated here). The criteria emissions components for the average 2001 light truck are nearly equally distributed (48% at the vehicle, 28% from the fuel cycle, and 24% embodied), albeit with a sum total of 1.22¢/mi – nearly 40% higher than the criteria emissions total of the average 2001 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. 663 g/mi for the average car) is then multiplied by the quasi-damage cost chosen for GHG emissions. In earlier editions of the *Green Book*, the GHG impact and health-related (criteria emissions) impact were the same by definition, under our assumption that GHG emissions were to be as important as criteria emissions in determining the average vehicle's EDX. The past two years, however, we have maintained the MY1999 damage cost factor for GHG emissions so that its weighting now accounts for 56% of the EDX of both the average car and light truck. With this assumed GHG damage cost factor, GHG impacts total 1.13¢/mi for the average car and 1.55¢/mi for the average truck. The GHG total breaks down as approximately 67% at the vehicle, 20% from the fuel-cycle, and 13% embodied for both the average car and light truck. The criteria- and GHG-related calculations are summarized in Tables 4(e) and 5(e), with resulting total EDXs of 2.01¢/mi and 2.77¢/mi, respectively, corresponding to Green Scores of 29 and 19.

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 because of the different regulatory treatment of cars and light trucks.

The EDX for the median passenger car is 2.07¢/mi, while that for the median light duty truck is 2.81¢/mi, about 36% higher.

Most light trucks fall into the LDT2 category. For an LDT2, for example, the low-emission (LEV) NO_x standard is 0.4 g/mi, half as stringent as the car standard of 0.2 g/mi. 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 2001 (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 account for nearly 50% of vehicle sales, the environmental degradation caused by MY2001 vehicles over their 12+ year lifetime will be dominated by 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:

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

with a = 100, b = 3 and c = 5.76¢/mi. A perfect score of 100 is unattainable since it would require an EDX of 0. Using the parameters shown, model year 2001 Green Scores range from 10 to 53, with an overall average of 23.

Table 6 presents EDX and Green Score results for a variety of past, present, and hypothetical future vehicles. A "pre-control" vehicle (e.g., a typical early 1960s car with no emissions controls, weighing 4500 lb. and getting 14 MPG) would have an EDX of 7.5¢/mi and a score of 2. A roughly doubled-efficiency (53 MPG) 2290 lb. gasoline that met the average Tier 2 NO_x standard of 0.07 g/mi would have an EDX of 1.08¢/mi and a score of 50. An ultra-clean gasoline vehicle meeting the PNGV (1994) tripled-efficiency goal would have a score of 60. Green Scores could become much higher if low-carbon fuels become available, potentially exceeding 90 for ultralight fuel-cell vehicles as envisioned by Lovins (1995).

When car shopping, most 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 7. 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 23, corresponding to an EDX of 2.42¢/mi) could obtain the Superior ranking. Details of the EDX distributions and exact cutpoints used for each class are provided in Appendix B.

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 C describes the updates made for this current edition.) Several areas for improvement are highlighted below and the authors look 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. Though not exactly following MOBILE 6, the U.S. EPA's proposed vehicle emissions model, we have attempted to keep the this year's estimates generally consistent with its proposed assumptions. When the 2001 edition of *ACEEE'S Green Book*™ was released, EPA was in the process of finalizing MOBILE 6, and we expect to draw heavily on it as well as its supporting data and analyses for the next edition of our guide. Vehicles certified to the more stringent California standards and the Tier 1 federal standards phased into the fleet since 1994 appear to have substantially better in-use performance than had been observed historically. The initial phase-in of the Supplemental Federal Test Procedure this year, which requires better control of off-cycle emissions, should 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

ACEEE's Green Book™ is still a relatively new concept, the first edition having been released in March 1998. The understandability and usefulness of green rating information and how it is presented need to 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. The authors 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

Environmental Concern	Phase of Product Life Cycle				
	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 $/kg pollutant [b]	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 Table A3.
b. See discussion and Table 3, below.
c. Derived from DeLuchi (1991), Table 9, estimate of 55.9 g/mi for a 2187 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]
Carbon Monoxide (CO)	0.03	0.006	0.003
Hydrocarbons (HC, or VOC)	0.34	0.068	0.034
Nitrogen Oxides (NO_X)	4.50	0.90	0.45
Sulfur Dioxide (SO_2)	21.26	4.25	2.13
Particulate Matter (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 2001 Car

Vehicle Attributes‡

Emissions Standard	LEV
Fuel Economy	28.2 MPG (unadjusted composite), 22.9 MPG (on-road)
Mass	3500 lb (1588 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	1.65	5.6	0.03	0.017
HC	0.075	1.99	0.15	0.34	0.005
NO_X	0.2	1.69	0.34	4.50	0.152
PM_{10}	0.08	0.21	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	10.2	0.45	0.34	0.015
SO_X	1.62	0.07	21.26	0.150
CH_4	4.43	0.19	--*	
N_2O	3.25	0.14	--*	
CO_2	8200	358	--*	

Subtotal (a): health-related pollution impacts at the vehicle (cents/mile) **0.400**

(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	0.27	0.007	0.0002
HC	6.13	0.27	0.068	0.002
NO_X	8.50	0.37	0.90	0.033
PM_{10}	0.96	0.04	7.22	0.030
SO_X	9.88	0.43	4.25	0.183
CH_4	16.6	0.73	--*	
N_2O	0.18	0.01	--*	
CO_2	2450	107	--*	

Subtotal (b): health-related pollution impacts from fuel supply (cents/mile) **0.249**

‡ The Average MY2001 Car was selected as the actual light duty vehicle most closely matching both fuel economy and vehicle weight estimates as identified in Heavenrich and Hellman (2000). This year, the Average Car is a 2001 Pontiac Grand Am, 2.4L 4-cyl, auto, with labeled fuel economy of 21/29 mpg (city/hwy). LEV vehicles were selected as the most representative emissions standard, given the introduction of NLEV in 2001.

† Ratio of estimated real-world emissions to emissions standard, resulting from the procedure described under "Estimating In-Use Tailpipe Emissions" in the text.

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

Table 4. EDX Calculation for an Average 2001 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	0.31	0.90	0.028
PM_{10}	0.0283	0.04	7.22	0.032
SO_X	0.243	0.39	4.25	0.164
CO_2	56.0	88.91	--*	
Subtotal (c): health-related pollution impacts from production phase (cents/mile)				**0.225**

(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	358.17	107.01	88.91	1	554.09
HC	0.59	0.27		2	1.73
NO_X	0.34	0.37	0.31	4	4.09
CO	5.61	0.27		5	29.41
CH_4	0.19	0.73		22	20.24
N_2O	0.14	0.01		355	53.19
Sum weighted by GWP	443.41	129.17	90.16		
Total CO_2-equivalent GHG emissions, grams per mile:					662.75
Assumed damage cost factor for GHG emissions, per kg CO_2-equivalent:					$0.0171
Subtotal (d): GHG impacts (cents/mile)					**1.133**

(e) Summary of EDX Calculation for an Average 2001 Car

Environmental Impact	Life Cycle Cost cents/mile
(a) At the vehicle health-related pollution	0.400
(b) Fuel cycle health-related pollution	0.249
(c) Embodied health-related pollution	0.225
Subtotal, health-related pollution (criteria emissions) impacts	0.875
(d) Subtotal, greenhouse gas impacts	1.133
TOTAL Environmental Damage Index (EDX)	**2.01**
Corresponding MY2001 Green Score	**29**

Table 5. Environmental Damage Index (EDX) Calculation for an Average 2001 Truck

Vehicle Attributes‡

Emissions Standard	LEV
Fuel Economy	20.5 MPG (unadjusted composite), 16.4 MPG (on-road)
Mass	4500 lb (2041 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	4.4	1.41	6.2	0.03	0.019
HC	0.1	1.81	0.18	0.34	0.006
NO_X	0.4	1.38	0.55	4.50	0.248
PM_{10}	0.1	0.21	0.02	36.12	0.076

Fuel-Dependent Emissions by species	Emission Factor grams/gallon	Emissions Rate grams/mile	Damage Cost $/kg	Life Cycle Cost cents/mile
Evaporative HC	10.2	0.62	0.34	0.021
SO_X	1.62	0.10	21.26	0.210
CH_4	4.43	0.27	--*	
N_2O	3.25	0.20	--*	
CO_2	8200	501	--*	

Subtotal (a): health-related pollution impacts at the vehicle (cents/mile) **0.580**

(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	0.38	0.007	0.0003
HC	6.13	0.37	0.068	0.003
NO_X	8.50	0.52	0.90	0.047
PM_{10}	0.96	0.06	7.22	0.042
SO_X	9.88	0.60	4.25	0.256
CH_4	16.6	1.02	--*	
N_2O	0.18	0.01	--*	
CO_2	2450	150	--*	

Subtotal (b): health-related pollution impacts from fuel supply (cents/mile) **0.348**

‡ The Average MY2001 Truck was selected as the actual light duty truck most closely matching both fuel economy and vehicle weight estimates as identified in Heavenrich and Hellman (2000). This year, the Average Truck is a 2001 Ford Explorer Sport Trac, 4.0L 6-cyl, auto, with labeled fuel economy of 16/20 mpg (city/hwy). LEV vehicles were selected as the most representative emissions standard, given the introduction of NLEV in 2001.

† Ratio of estimated real-world emissions to emissions standard, resulting from the procedure described under "Estimating In-Use Tailpipe Emissions" in the text.

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

Table 5. EDX Calculation for an Average 2001 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	0.40	0.90	0.036
PM_{10}	0.0283	0.06	7.22	0.042
SO_X	0.243	0.50	4.25	0.211
CO_2	56.0	114.31	--*	
Subtotal (c): health-related pollution impacts from production phase (cents/mile)				**0.289**

(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	500.73	149.61	114.31	1	764.65
HC	0.80	0.37		2	2.36
NO_X	0.55	0.52	0.40	4	5.89
CO	6.19	0.38		5	32.87
CH_4	0.27	1.02		22	28.29
N_2O	0.20	0.01		355	74.36
Sum weighted by GWP	611.91	180.59	115.92		
Total CO_2-equivalent GHG emissions, grams per mile:					908.42
Assumed damage cost factor for GHG emissions, per kg CO_2-equivalent:					$0.0171
Subtotal (d): GHG impacts (cents/mile)					**1.553**

(E) Summary of EDX Calculation for an Average 2001 Car

Environmental Impact	Life Cycle Cost cents/mile
(a) At the vehicle health-related pollution	0.580
(b) Fuel cycle health-related pollution	0.348
(c) Embodied health-related pollution	0.289
Subtotal, health-related pollution (criteria emissions) impacts	1.217
(d) Subtotal, greenhouse gas impacts	1.553
TOTAL Environmental Damage Index (EDX)	**2.77**
Corresponding MY2001 Green Score	**19**

Table 6. Green Scores for Selected Model Year 2001 Vehicles plus Past and Future Vehicles

Vehicle	Weight lb [a]	Efficiency MPG [b]	Emissions Standard	EDX ¢/mi	Green Score
Fuel cell vehicle, renewable hydrogen [c]	1690	80	ZEV	0.18	88
3x passenger car, ultra-clean PNGV [d]	2290	80	ULEV-2	0.77	60
Best 2001 vehicle: Honda Civic GX [e]	2750	38	SULEV	0.97	53
Contemporary Hybrid: Toyota Prius	3000	58	SULEV	1.03	51
2x passenger car, Tier 2 [f]	2290	53	Tier 2	1.08	50
Well-rated gasoline car: Toyota Echo	2250	43	LEV	1.40	41
Average 2001 car [g]	3500	28	LEV	2.01	29
Average 2001 light truck [h]	4500	21	LEV	2.77	19
Average 1991 car [i]	3153	28	Tier 0	2.99	17
Worst 2001 vehicle: Full-Size Pickup	5500	14	Tier 1	4.12	10
Pre-control car (1960s vintage) [j]	4500	14	None	7.50	2

Notes:

a. Inertial test weight (or curb weight plus 300 lb).

b. Composite unadjusted city/highway average gasoline equivalent MPG, based on 125,000 Btu/gallon.

c. Assumes zero vehicle and fuel cycle emissions for hydrogen produced by solar-powered electrolysis, that curb weight is cut by half, and a 1%/yr decline in manufacturing emissions through 2010 (the assumed year of vehicle manufacture).

d. Assumes all CO, HC, and NO_x tailpipe emissions meet California's 120,000-mi ULEV-2 standard; (ULEV-2 reduces NO_X to 0.05 g/mi); refer to Table A1d. PM emissions are determined by multiplying the ULEV PM total lifetime estimate (0.008 g/mi) by the ratio of the 120,000-mi ULEV-2 NO_x standard to the 120,000-mi ULEV NO_x standard (0.07/0.30). Evaporative hydrocarbon emissions are determined by multiplying our estimate of ULEV evaporative emissions, as noted in Delucchi (1997b) and shown in Table A2a, by the ratio of LEV to LEV II 3-day diurnal tests (0.5/2.0 g/test).

e. CNG fuel economy is given as gasoline-equivalent MPG.

f. Vehicle efficiency and mass are based on Duleep (1997). Real world tailpipe emissions are assumed to be meeting the Tier 2 LDV Bin No. 5 emissions standard (corresponding to the manufacturer's average full life NO_x standard of 0.07 g/mi), as noted in the Federal Register (2000). Evaporative emissions are determined by multiplying our estimate of Tier 1 evaporative emissions, as noted in Delucchi (1997b) and shown in Table A2a, by the ratio of Tier 2 to Tier 1 three-day diurnal tests (0.95/2.0 g/test).

g. As defined in Table 4.

h. As defined in Table 5.

i. Assumes Tier 0 exhaust emissions standards, and MY2000 (non-SFTP) Tier 1 evaporative emissions and real world emission factors (see DeCicco and Kliesch 2000, Tables A1a and A2a).

j. Assumes vehicle emissions of 84 g/mi CO, 20 g/mi HC, and 4 g/mi NO_X (Hwang 1997, 2), and the Tier 0 PM standard (0.20 g/mi).

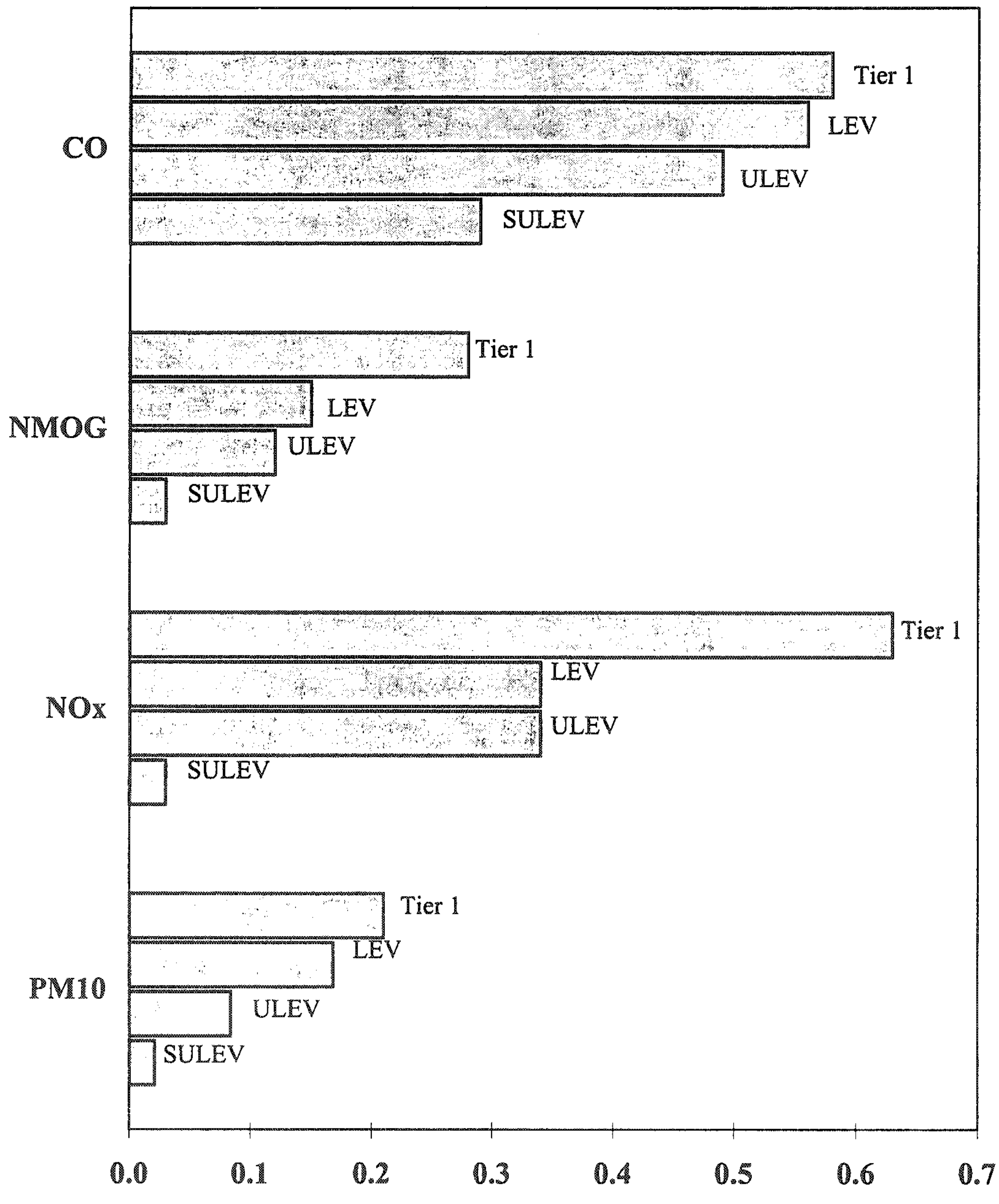
Table 7. Percentile Guidelines and Symbols for Within-Class Vehicle Rankings

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

Notes:

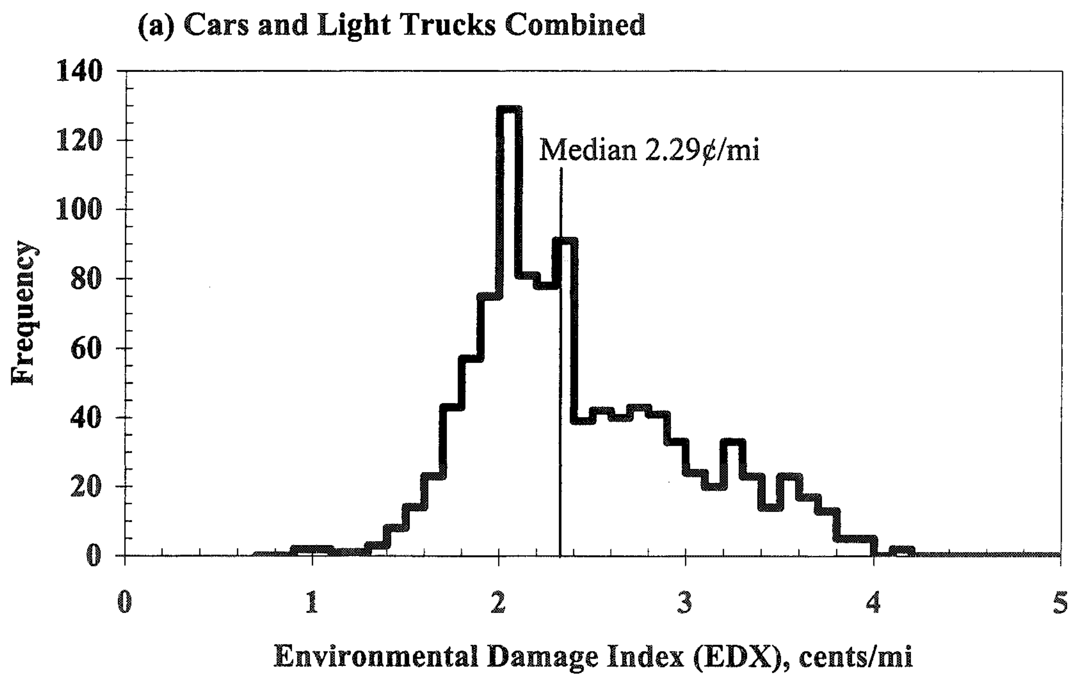
a. For a Superior ranking, a vehicle must also have a Green Score no less than 23, corresponding to the MY2001 combined car-truck average EDX of 2.42¢/mi.

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



Emissions Rate
(NMOG and NO_x in g/mi, CO in 10 g/mi, PM_{10} in g/10 mi)

Figure 2. Distribution of Environmental Damage Index for Model Year 2001



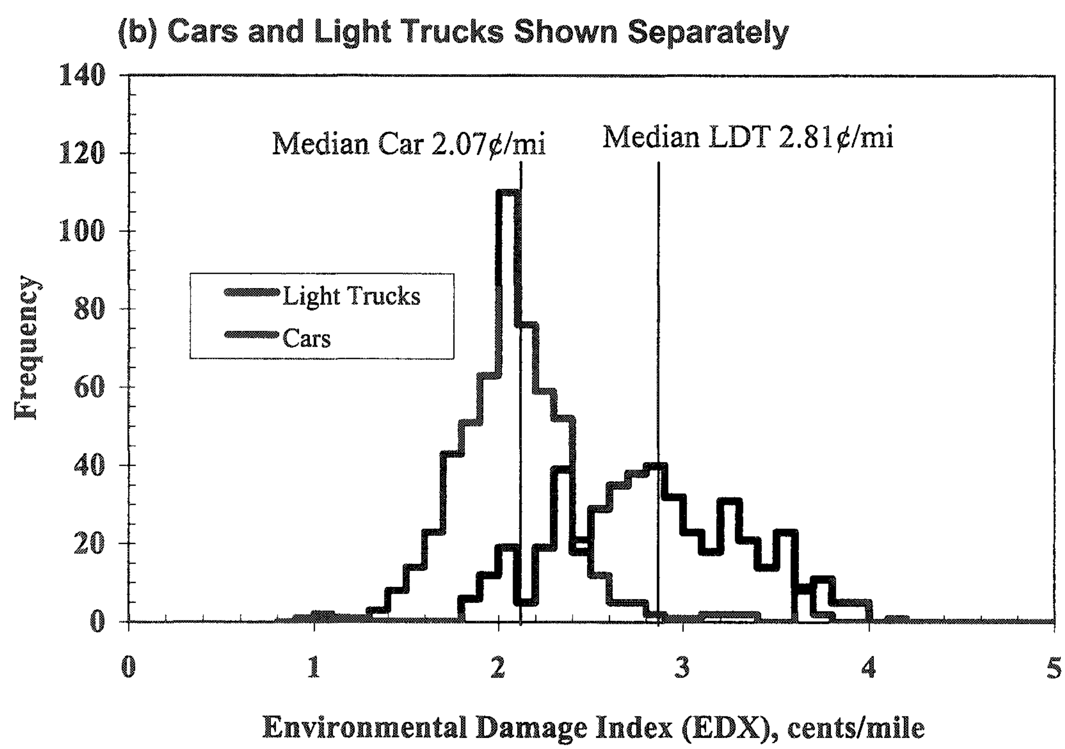
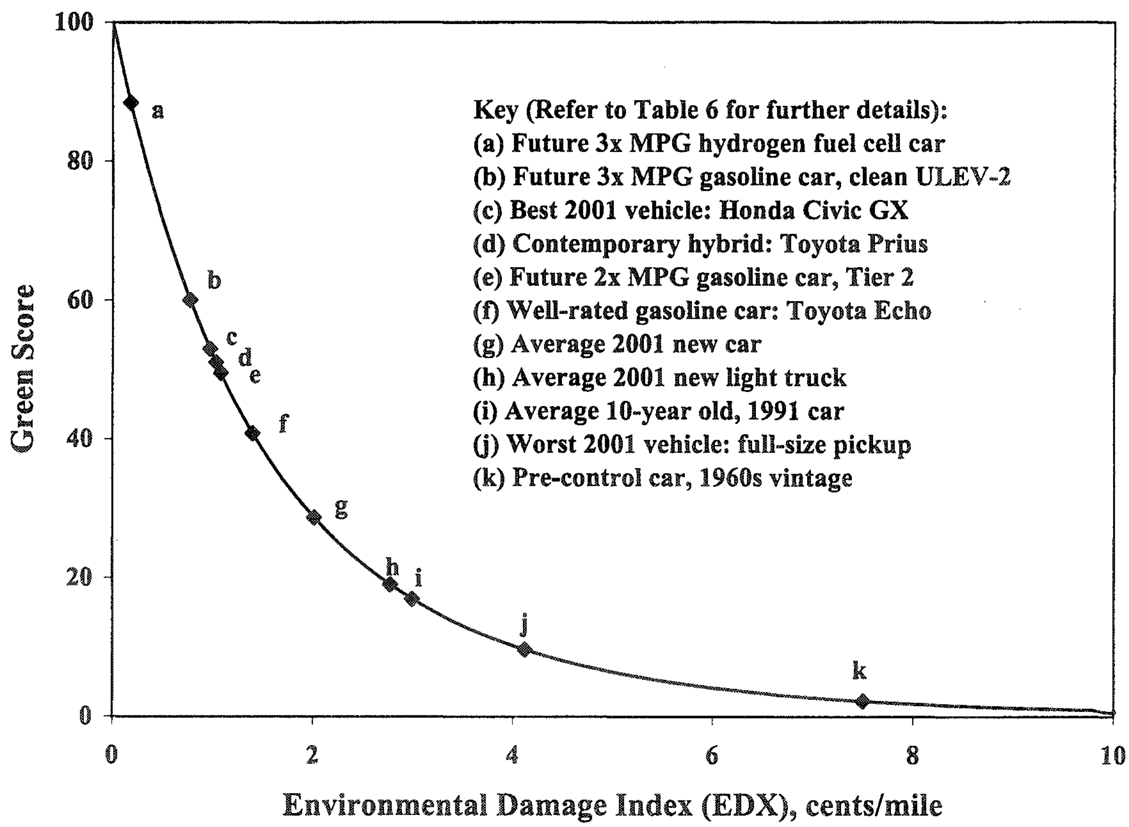


Figure 3. Green Score vs. Environmental Damage Index, with Example Vehicles



Appendix A

DETAILS OF EMISSIONS CHARACTERIZATION ESTIMATES

Table A1. Lifetime Average Tailpipe Emissions Estimates

This multi-part table documents our estimates of tailpipe emissions from gasoline, diesel and compressed natural gas (CNG) vehicles according to emissions standards. All vehicles within a given light duty class and fuel type 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 Subtables:

a	Tier 1 Gasoline Vehicles
b	Gasoline Transitional Low Emission Vehicles (TLEV)
c	Gasoline Low Emission Vehicles (LEV)
d	Gasoline Ultra-Low Emission Vehicles (ULEV)
e	Gasoline Super Ultra-Low Emission Vehicles (SULEV)
f	Tier 1 Diesel Vehicles
g	Ultra-Low Emission CNG Vehicles (ULEV)
h	Super Ultra-Low Emission CNG Vehicles (SULEV)

		Load Scaling Factors		
Weight Classifications for Federally Certified Vehicles		Median ITW		Ratio
LDV	All passenger cars	3500	a	1.00
LDT1	GVW 0-6000 lb and LVW 0-3750 lb	3500	a	1.00
LDT2	GVW 0-6000 lb and LVW 3751-5750 lb	4500	a	1.29
LDT3	GVW 6001-8500 lb and ALVW 0-5750 lb	5275	b	1.51
LDT4	GVW 6001-8500 lb and ALVW 5751-8500 lb	6000	a	1.71
HDT	(Class 2B) GVW 8501-10000 lb	6300	c, d	1.05

Weight Classifications for California Certified Vehicles		Median ITW		Ratio
PC	All passenger cars	3500	a	1.00
LDT1-CA	GVW 0-6000 lb, LVW 0-3750 lb	3500	a	1.00
LDT2-CA	GVW 0-6000 lb, LVW 3751-5750 lb	4500	a	1.29
MDV2-CA	GVW 6001-14000 lb, ALVW 3751-5750 lb	5275	b	1.51
MDV3-CA	GVW 6001-14000 lb, ALVW 5751-8500 lb	6000	a	1.71
MDV4-CA	GVW 6001-14000 lb, ALVW 8501-10000 lb	6300	c, d	1.05

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.

Table A1. Lifetime Average Tailpipe Emissions Estimates (continued)

All Tier 1, LEV, and ULEV HC and NO_x emissions estimates for gasoline vehicles (LDV, LDT1, LDT2, LDT3, and LDT4) are derived from an EPA spreadsheet model incorporating proposed MOBILE 6 methodology. These estimates include off-cycle effects for HC and NO_x; thus off-cycle adjustments are not necessary for these pollutants. Raw on-cycle CO emission rate data are also provided by EPA. Off-cycle CO adjustments are assumed to scale with vehicle weight (load). Emission rates for Class 2B trucks (HDTs) are scaled up from the basic rates as described below and shown in the subtables. PM emissions are estimated as described in the subtables.

Scaling Off-Cycle CO Emissions Factors, based on SFTP Implementation (gasoline)

Tier 1 Benefit	72%
LEV Benefit	
LDV/T1	79%
LDT2	78%
LDT3	78%
LDT4	79%
A/C Penalty	(-) 20%

Scaling Emissions Factors from Cars to Light Duty Trucks (diesel)

Source of emissions

Base In-Use	Scales with ratio of LDT Std : LDV Std
Off-cycle	Assumes 28% off-cycle, 78% in-use. See Table A1f

Scaling Emissions Factors from LDT4s to Class 2B HDTs (gasoline and diesel)

Source of emissions

Lifetime Avg. Estimate	Scales with ratio of HDT weight : LDV4 weight

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.

Table A1a. Tailpipe Emissions for a Gasoline Federally-Certified (Tier 1) Vehicle
(all rates in g/mi)

LDV	CO (a)	HC (b)	NO_x (b)	PM_{10} (i)
Emissions Standard (c, g)	*3.4*	*0.25*	*0.40*	*0.08*
Base In-Use Estimate	4.2	0.28	0.63	
Off-Cycle Adjustment (d)	1.6	--	--	
Lifetime Avg Estimate	**5.8**	**0.28**	**0.63**	**0.02**
Ratio to Standard	*1.71*	*1.11*	*1.58*	*0.26*

LDT1	CO	HC	NO_x	PM_{10} (j)
Emissions Standard (g)	*3.4*	*0.25*	*0.40*	*0.08*
Base In-Use Estimate	4.2	0.29	0.65	
Off-Cycle Adjustment	1.6	--	--	
Lifetime Avg Estimate	**5.8**	**0.29**	**0.65**	**0.02**
Ratio to Standard	*1.71*	*1.15*	*1.62*	*0.26*

LDT2	CO	HC	NO_x	PM_{10} (j)
Emissions Standard (g)	*4.4*	*0.32*	*0.70*	*0.08*
Base In-Use Estimate	4.5	0.35	0.99	
Off-Cycle Adjustment	1.9	--	--	
Lifetime Avg Estimate	**6.4**	**0.35**	**0.99**	**0.02**
Ratio to Standard	*1.46*	*1.08*	*1.42*	*0.26*

LDT3 / MDV2	CO	HC	NO_x	PM_{10} (h)
Emissions Standard (g)	*4.4*	*0.32*	*0.70*	*0.1*
Base In-Use Estimate	4.5	0.34	0.99	
Off-Cycle Adjustment	2.1	--	--	
Lifetime Avg Estimate	**6.6**	**0.34**	**0.99**	**0.02**
Ratio to Standard	*1.49*	*1.08*	*1.41*	*0.21*

LDT4 / MDV3	CO (e)	HC	NO_x	PM_{10} (h)
Emissions Standard (g)	*5.0*	*0.39*	*1.10*	*0.12*
Base In-Use Estimate	5.1	0.40	1.44	
Off-Cycle Adjustment	2.4	--	--	
Lifetime Avg Estimate	**7.5**	**0.40**	**1.44**	**0.03**
Ratio to Standard	*1.50*	*1.03*	*1.31*	*0.21*

Class 2B HDT (f)

Load Scaling Factor: 1.05	CO	HC	NO_x	PM_{10}
Lifetime Avg Estimate	**7.9**	**0.42**	**1.51**	**0.03**

Table A1a. Tailpipe Emissions for a Gasoline Federally-Certified (Tier 1) Vehicle (continued)

Notes:

a. Raw CO emission rate data (including ZMLs) provided by personal communication with EPA. Deterioration rates interpolated from raw EPA data. Flex point selected as best approximation from raw data.

b. Weighted average of RFG and Conventional gasoline values (33% RFG) from the EPA (Koupal 1999) FER model.

c. A PM_{10} standard is not specified for gasoline vehicles; the diesel PM10 standard is shown.

d. CO emission rates were provided by EPA for FTP (on-cycle) only (EPA 1999a). CO off-cycle adjustments are derived to account for both control improvement-related emissions reductions, and a modest CO increase due to air conditioning loading, as described in the text and Table A1. For HC and NO_x, FER includes off-cycle effects, so off-cycle adjustment is not needed.

e. CO FTP emission rates are provided by EPA for LDV/LDT1 and LDT2/LDT3 (EPA 1999a). Since no CO data was provided for LDT4s, we calculate LDT4 values as the FTP subtotal estimate of LDT3, multiplied by the ratio of the LDT4 standard to the LDT3 standard.

f. Class 2B Truck emissions are scaled from LDT4 emissions by a load-scaling factor. The Load Scaling Factor is the ratio of average Class 2B:LDT4 vehicle weight, 1.05, as described in Table A1.

g. The 50,000-mile standard is shown unless otherwise noted. Federal LDT3 and California MDV2 50,000-mile standards are identical, as are LDT4 and MDV3 standards. The useful life standards differ slightly.

h. For LDT3/MDV2 and LDT4/MDV3, there is no 50,000 mile standard, only a full-life, 120,000 mile standard. Since there is no 50,000 mile PM_{10} standard, we adjust values by the ratio of the half-life to full-life standard for LDT2s (0.08 g/mi / 0.10 g/mi).

i. Delucchi 1997b (GHG model Sheet H: Cell B21) estimates gasoline vehicle in-use PM_{10} emissions at 0.042 g/mi, based on a review of available measurements and comparison to EPA's Particulate emissions model (PART). For our calculation procedure, we represent these emissions by applying a downward adjustment factor to a "standard" in this case taken to be the same as the diesel PM_{10} standard. Based on recent evaluations of PM exhaust from vehicles with 3-way catalysts, we reduce this estimate by 50%.

j. The ratio of actual to standard emissions is assumed to be the same for LDTs as for LDVs; the LDT standard is multiplied by this ratio to estimate actual emissions.

Table A1b. Tailpipe Emissions for a Gasoline Transitional Low-Emission Vehicle (TLEV)
(all rates in g/mi)

LDV	**CO** (a)	**HC** (b)	**NO_x** (c)	**PM_{10}** (d, e)
Emissions Standard	*3.4*	*0.125*	*0.40*	*0.08*
Base In-Use Estimate	4.2	0.21	0.62	
Off-Cycle Adjustment	1.6	--	--	
Lifetime Avg Estimate	**5.8**	**0.21**	**0.62**	**0.02**
Ratio to Standard	*1.71*	*1.68*	*1.56*	*0.21*

LDT1	**CO**	**HC**	**NO_x**	**PM_{10}** (f)
Emissions Standard	*3.4*	*0.125*	*0.40*	*0.08*
Base In-Use Estimate	4.2	0.22	0.64	
Off-Cycle Adjustment	1.6	--	--	
Lifetime Avg Estimate	**5.8**	**0.22**	**0.64**	**0.02**
Ratio to Standard	*1.71*	*1.76*	*1.59*	*0.21*

LDT2	**CO**	**HC**	**NO_x**	**PM_{10}** (f)
Emissions Standard	*4.4*	*0.16*	*0.70*	*0.1*
Base In-Use Estimate	4.5	0.26	0.98	
Off-Cycle Adjustment	1.9	--	--	
Lifetime Avg Estimate	**6.4**	**0.26**	**0.98**	**0.02**
Ratio to Standard	*1.46*	*1.62*	*1.40*	*0.21*

Notes:

a. TLEV CO standard is the same as Tier 1 standard, so we use the Tier 1 estimate for TLEVs.

b. FER does not have an HC estimate for TLEV emissions. TLEV HC emissions are computed as an average of Tier 1 and LEV emissions levels at 40 ppm.

c. FER does not have a NO_x estimate for TLEV emissions. TLEV NO_x standard is the same as Tier 1 standards. We use the FER estimate for Tier 1 vehicles at 40 ppm.

d. A PM_{10} standard is not specified for gasoline vehicles; the diesel PM_{10} standard is shown. For TLEVs, there is no 50,000 mile standard, only a full-life 120,000 mile standard.

e. We maintain the same ratio (0.26 for 50,000 mile standards and 0.21 for full-life standards) of actual to standard PM10 emissions as used for Tier 1 vehicles (see Notes (h,i) in Table A1a)

f. The ratio of actual to standard emissions is assumed to be the same for LDTs as for LDVs; the LDT standard is multiplied by this ratio to estimate actual emissions.

Table A1c. Tailpipe Emissions for a Gasoline Low-Emission Vehicle (LEV)
(all rates in g/mi)

LDV	CO (a)	HC (b)	NO_x (b)	PM_{10} (f, g)
Emissions Standard	*3.4*	*0.075*	*0.20*	*0.08*
Base In-Use Estimate	4.2	0.15	0.34	
Off-Cycle Adjustment (c)	1.4	--	--	
Lifetime Avg Estimate	**5.6**	**0.15**	**0.34**	**0.02**
Ratio to Standard	*1.65*	*1.99*	*1.69*	*0.21*

LDT1	CO	HC	NO_x	PM_{10} (h)
Emissions Standard	*3.4*	*0.075*	*0.20*	*0.08*
Base In-Use Estimate	4.2	0.16	0.35	
Off-Cycle Adjustment	1.4	--	--	
Lifetime Avg Estimate	**5.6**	**0.16**	**0.35**	**0.02**
Ratio to Standard	*1.65*	*2.11*	*1.76*	*0.21*

LDT2	CO	HC	NO_x	PM_{10} (h)
Emissions Standard	*4.4*	*0.10*	*0.40*	*0.1*
Base In-Use Estimate	4.5	0.18	0.55	
Off-Cycle Adjustment	1.7	--	--	
Lifetime Avg Estimate	**6.2**	**0.18**	**0.55**	**0.02**
Ratio to Standard	*1.41*	*1.81*	*1.38*	*0.21*

LDT3 / MDV2	CO	HC	NO_x	PM_{10} (h)
Emissions Standard	*4.4*	*0.16*	*0.40*	*0.1*
Base In-Use Estimate	4.5	0.24	0.57	
Off-Cycle Adjustment	1.8	--	--	
Lifetime Avg Estimate	**6.3**	**0.24**	**0.57**	**0.02**
Ratio to Standard	*1.44*	*1.48*	*1.43*	*0.21*

LDT4 / MDV3 (d)	CO	HC	NO_x	PM_{10} (h)
Emissions Standard	*5.0*	*0.195*	*0.60*	*0.12*
Base In-Use Estimate	5.1	0.27	0.80	
Off-Cycle Adjustment	2.0	--	--	
Lifetime Avg Estimate	**7.1**	**0.27**	**0.80**	**0.03**
Ratio to Standard	*1.43*	*1.39*	*1.33*	*0.21*

Class 2B HDT (e)

Load Scaling Factor: 1.05	CO	HC	NO_x	PM_{10} (h)
Lifetime Avg Estimate	**7.5**	**0.28**	**0.84**	**0.03**

Table A1c. Tailpipe Emissions for a Gasoline Low-Emission Vehicle (LEV) (continued)

Notes:

a. Raw CO emission rate data (including ZMLs) provided by personal communication with EPA. Deterioration rates interpolated from raw EPA data. Flex point selected as best approximation from raw data.
b. Weighted average of RFG and Conventional gasoline values (33% RFG) from the EPA (Koupal 1999) FER model.
c. CO emission rates were provided by EPA for FTP (on-cycle) only (EPA 1999a). CO off-cycle adjustments are derived to account for both control improvement-related emissions reductions, and a modest CO increase due to air conditioning loading, as described in the text and Table A1. For HC and NO_x, FER includes off-cycle effects, so off-cycle adjustment is not needed.
d. CO FTP emission rates are provided by EPA for LDV/LDT1 and LDT2/LDT3 (EPA 1999a). Since no CO data was provided for LDT4s, we calculate LDT4 values as the FTP subtotal estimate of LDT3, multiplied by the ratio of the LDT4 standard to the LDT3 standard.
e. Class 2B Truck emissions are scaled from LDT4 emissions by a load-scaling factor. The Load Scaling Factor is the ratio of average Class 2B:LDT4 vehicle weight, 1.05, as described in Table A1a.
f. A PM_{10} standard is not specified for gasoline vehicles; the diesel PM_{10} standard is shown. For LEVs, there is no 50,000-mile standard, only a full-life 120,000 mile standard.
g. We maintain the same ratio (0.26 for 50,000 mile standards and 0.21 for full-life standards) of actual to standard PM10 emissions as used for Tier 1 vehicles (see Notes (h,i) in Table A1a)
h. The ratio of actual to standard emissions is assumed to be the same for LDTs as for LDVs; the LDT standard is multiplied by this ratio to estimate actual emissions.

Table A1d. Tailpipe Emissions for a Gasoline Ultra-Low-Emission Vehicle (ULEV)
(all rates in g/mi)

LDV	CO (a)	HC (b)	NO_x (b)	PM_{10} (e, f)
Emissions Standard	*1.7*	*0.04*	*0.20*	*0.04*
Base In-Use Estimate	3.6	0.12	0.34	
Off-Cycle Adjustment (c)	1.3	--	--	
Lifetime Avg Estimate	**4.9**	**0.12**	**0.34**	**0.008**
Ratio to Standard	*2.87*	*2.94*	*1.69*	*0.21*

LDT1	CO	HC	NO_x	PM_{10} (g)
Emissions Standard	*1.7*	*0.04*	*0.20*	*0.04*
Base In-Use Estimate	3.6	0.13	0.35	
Off-Cycle Adjustment	1.3	--	--	
Lifetime Avg Estimate	**4.9**	**0.13**	**0.35**	**0.008**
Ratio to Standard	*2.87*	*3.16*	*1.76*	*0.21*

LDT2	CO	HC	NO_x	PM_{10} (g)
Emissions Standard	*2.2*	*0.05*	*0.40*	*0.05*
Base In-Use Estimate	3.6	0.14	0.55	
Off-Cycle Adjustment	1.5	--	--	
Lifetime Avg Estimate	**5.2**	**0.14**	**0.55**	**0.011**
Ratio to Standard	*2.35*	*2.70*	*1.38*	*0.21*

LDT3 / MDV2	CO	HC	NO_x	PM_{10} (g)
Emissions Standard	*4.4*	*0.10*	*0.40*	*0.05*
Base In-Use Estimate	3.6	0.18	0.57	
Off-Cycle Adjustment	1.7	--	--	
Lifetime Avg Estimate	**5.3**	**0.18**	**0.57**	**0.011**
Ratio to Standard	*1.20*	*1.81*	*1.43*	*0.21*

LDT4 / MDV3 (d)	CO	HC	NO_x	PM_{10} (g)
Emissions Standard	*5.0*	*0.117*	*0.60*	*0.06*
Base In-Use Estimate	4.1	0.20	0.80	
Off-Cycle Adjustment	1.8	--	--	
Lifetime Avg Estimate	**6.0**	**0.20**	**0.80**	**0.013**
Ratio to Standard	*1.20*	*1.69*	*1.33*	*0.21*

Table A1d. Tailpipe Emissions for a Gasoline Ultra-Low-Emission Vehicle (ULEV) (continued)

Notes:

a. Raw CO emission rate data (including ZMLs) provided by personal communication with EPA. Deterioration rates interpolated from raw EPA data. Flex point selected as best approximation from raw data.
b. Weighted average of RFG and Conventional gasoline values (33% RFG) from the EPA (Koupal 1999) FER model.
c. CO emission rates were provided by EPA for FTP (on-cycle) only (EPA 1999a). CO off-cycle adjustments are derived to account for both control improvement-related emissions reductions, and a modest CO increase due to air conditioning loading, as described in the text and Table A1. For HC and NO_x, FER includes off-cycle effects, so off-cycle adjustment is not needed.
d. CO FTP emission rates are provided by EPA for LDV/LDT1 and LDT2/LDT3 (EPA 1999a). Since no CO data was provided for LDT4s, we calculate LDT4 values as the FTP subtotal estimate of LDT3, multiplied by the ratio of the LDT4 standard to the LDT3 standard.
e. A PM_{10} standard is not specified for gasoline vehicles; the diesel PM_{10} standard is shown. For LEVs, there is no 50,000-mile standard, only a full-life 120,000 mile standard.
f. We maintain the same ratio (0.26 for 50,000 mile standards and 0.21 for full-life standards) of actual to standard PM10 emissions as used for Tier 1 vehicles (see Notes (h,i) in Table A1a)
g. The ratio of actual to standard emissions is assumed to be the same for LDTs as for LDVs; the LDT standard is multiplied by this ratio to estimate actual emissions.

Table A1e. Tailpipe Emissions for a Gasoline Super-Ultra-Low-Emission Vehicle (SULEV)
(all rates in g/mi)

LDV	CO	NMOG	NO_x	PM_{10}
Emissions Standard (a)	*1.0*	*0.01*	*0.02*	*0.01*
Lifetime Avg Estimate	**2.9**	**0.03**	**0.03**	**0.002**
Ratio of Actual to Standard (b)	*2.87*	*2.94*	*1.69*	*0.21*

Notes:

a. The LDV SULEV standard is adopted from the LEV II 120,000-mile exhaust standard

b. The ratio of actual to standard emissions is assumed to be the same for SULEV LDVs as it is for ULEV LDVs.

Table A1f. Tailpipe Emissions for a Tier 1 Diesel Vehicle (Tier 1-D)
(all rates in g/mi)

LDV	**CO** (a)	**NMHC** (a)	**NO_x** (a)	**PM_{10}** (e)
Emissions Standard	*3.4*	*0.25*	*1.0*	*0.08*
Base In-Use Estimate	1.4	0.47	1.05	
Off-Cycle Adjustment (b)	0.5	0.18	0.41	
Lifetime Avg Estimate	**1.9**	**0.65**	**1.46**	**0.17**
Ratio to Standard	*0.57*	*2.61*	*1.46*	*2.1*

LDT1

Load Scaling Factor: 1.00	**CO**	**NMHC**	**NO_x**	**PM_{10}** (f)
Emissions Standard	*3.4*	*0.25*	*1.0*	*0.08*
Base In-Use Estimate (c)	1.4	0.47	1.05	
Off-Cycle Adjustment	0.5	0.18	0.41	
Lifetime Avg Estimate	**1.9**	**0.65**	**1.46**	**0.17**
Ratio to Standard	*0.57*	*2.61*	*1.46*	*2.1*

LDT2

Load Scaling Factor: 1.29	**CO**	**NMHC**	**NO_x**	**PM_{10}** (g)
Emissions Standard	*4.4*	*0.32*	*0.97*	*0.08*
Base In-Use Estimate (c)	1.6	0.67	1.21	
Off-Cycle Adjustment	0.6	0.26	0.47	
Lifetime Avg Estimate	**2.2**	**0.93**	**1.68**	**0.17**
Ratio to Standard	*0.50*	*2.91*	*1.73*	*2.1*

LDT3 / MDV2

Load Scaling Factor: 1.51	**CO**	**NMHC**	**NO_x**	**PM_{10}** (g)
Emissions Standard	*4.4*	*0.32*	*0.98*	*0.1*
Base In-Use Estimate (c)	1.6	0.67	1.22	
Off-Cycle Adjustment	0.6	0.26	0.48	
Lifetime Avg Estimate	**2.2**	**0.93**	**1.70**	**0.17**
Ratio to Standard	*0.50*	*2.91*	*1.73*	*1.68*

LDT4 / MDV3

Load Scaling Factor: 1.71	**CO**	**NMHC**	**NO_x**	**PM_{10}** (g)
Emissions Standard	*5.0*	*0.39*	*1.53*	*0.12*
Base In-Use Estimate (c)	1.8	0.82	1.91	
Off-Cycle Adjustment	0.7	0.32	0.74	
Lifetime Avg Estimate	**2.5**	**1.13**	**2.65**	**0.20**
Ratio to Standard	*0.50*	*2.91*	*1.73*	*1.68*

Class 2B HDT (d)

Load Scaling Factor: 1.05	**CO**	**NMHC**	**NO_x**	**PM_{10}**
Lifetime Avg Estimate	**2.6**	**1.19**	**2.78**	**0.21**

Table A1f. Tailpipe Emissions for a Tier 1 Diesel Vehicle (Tier 1-D) (continued)

Notes:

a. EPA (1999c). EPA assumes the same diesel emission factors as Mobile 5b. HC, CO, and NO_x ZML and Deterioration rates located on pp. 19, 21, 23.

b. The Supplemental Federal Test Procedure (SFTP) Final Rule (Federal Register 1996) assumes apportions emissions as 28% off-cycle and 72% on-cycle. We adopt this apportionment because EPA does not provide estimates for off-cycle diesel LDVs and LDTs.

c. EPA (1999c). All LDTs are assumed to have the same rate, i.e. no distinction is made between LDT1, LDT2, LDT3, and LDT4. We assume that the stated MOBILE 6 rates apply to LDT2s and multiply the FTP subtotal estimate by the ratio of LDT3 and 4 standards to the LDT 2 standard. LDT1 standards are the same as LDVs, so we assume the same emission rates. Standards are at 50,000 miles, with the exception of NO_x LDT2-4, for which only 120,000-mile standards exist.

d. Class 2B Truck emissions are scaled from LDT4 emissions by a load-scaling factor. The Load Scaling Factor is the ratio of average Class 2B:LDT4 vehicle weight, 1.05, as described in Table A1.

e. Delucchi does not estimate PM_{10} emissions from light-duty diesel vehicles. Wang 1996 (Table 10, p. 43) estimates the ratio of (0.12 g/mi / 0.03 g/mi) = 4 for diesel-to-gasoline PM_{10} emissions; we apply the ratio to the Delucchi 1997b (Sheet H: cell B21) estimate of 0.042 g/mi for gasoline vehicles, to obtain 0.17 g/mi PM_{10} for diesel LDVs.

f. The off-cycle emission rates for LDVs are multiplied by the load-scaling factor to obtain LDT rates, as described in the Table A1.

g. Diesel PM_{10} emissions were estimated by applying the LDV actual-to-standard ratio to the PM standard for these classes. Since there is no 50,000 mile PM standard for LDT2/MDV3 or LDT4/MDV3, we adjust values by the ratio of the half-life to full-life standard for LDT2s (0.08 g/mi : 0.10 g/mi).

Table A1g. Tailpipe Emissions for a CNG Ultra-Low-Emission Vehicle (ULEV)
(all rates in g/mi)

LDV	**CO**	**NMOG**	**NO_x**	**PM_{10}**
Emissions Standard (a, b)	*1.7*	*0.04*	*0.20*	*0.040*
Lifetime Avg Estimate (c)	**3.1**	**0.03**	**0.25**	**0.001**
Ratio of Actual to Standard	*1.82*	*0.80*	*1.24*	*0.025*

LDT1	**CO**	**NMOG**	**NO_x**	**PM_{10}**
Emissions Standard (a, b)	*1.7*	*0.04*	*0.20*	*0.040*
Lifetime Avg Estimate (c)	**3.1**	**0.03**	**0.25**	**0.001**
Ratio of Actual to Standard (d)	*1.82*	*0.80*	*1.24*	*0.025*

LDT2	**CO**	**NMOG**	**NO_x**	**PM_{10}**
Emissions Standard (a, b)	*2.2*	*0.05*	*0.40*	*0.050*
Lifetime Avg Estimate (c)	**4.0**	**0.04**	**0.50**	**0.001**
Ratio of Actual to Standard (d)	*1.82*	*0.80*	*1.24*	*0.025*

LDT3 / MDV2	**CO**	**NMOG**	**NO_x**	**PM_{10}**
Emissions Standard (a, b)	*4.4*	*0.10*	*0.40*	*0.050*
Lifetime Avg Estimate (c)	**8.0**	**0.08**	**0.50**	**0.001**
Ratio of Actual to Standard (d)	*1.82*	*0.80*	*1.24*	*0.025*

LDT4 / MDV3	**CO**	**NMOG**	**NO_x**	**PM_{10}**
Emissions Standard (a, b)	*5.0*	*0.117*	*0.60*	*0.060*
Lifetime Avg Estimate (c)	**9.1**	**0.09**	**0.74**	**0.002**
Ratio of Actual to Standard (d)	*1.82*	*0.80*	*1.24*	*0.025*

Notes:

a. The 50,000-mile standard.

b. A PM_{10} standard is not specified for CNG vehicles; the diesel PM_{10} standard is shown.

c. GREET v.1.5 (Wang 1999). Worksheet Vehicles:G 56-60. Assumes "near term technology."

d. The ratio of actual to standard emissions is assumed to be the same for LDTs as it is for LDVs; the LDT standard is multiplied by this ratio to estimate actual emissions.

Table A1h. Tailpipe Emissions for a CNG Super-Ultra-Low-Emission Vehicle (SULEV)
(all rates in g/mi)

LDV	**CO**	**NMOG**	**NO_x**	**PM_{10}**
Emissions Standard (a)	*1.0*	*0.01*	*0.02*	*0.010*
Lifetime Avg Estimate	**1.8**	**0.01**	**0.02**	**0.000**
Ratio of Actual to Standard	*1.82*	*0.80*	*1.24*	*0.025*

MDV2	**CO**	**NMOG**	**NO_x**	**PM_{10} (c)**
Emissions Standard (b)	*2.2*	*0.05*	*0.2*	*0.05*
Lifetime Avg Estimate	**4.0**	**0.04**	**0.25**	**0.001**
Ratio of Actual to Standard	*1.82*	*0.80*	*1.24*	*0.025*

MDV3	**CO**	**NMOG**	**NO_x**	**PM_{10} (c)**
Emissions Standard (b)	*2.5*	*0.059*	*0.3*	*0.06*
Lifetime Avg Estimate	**4.6**	**0.05**	**0.37**	**0.002**
Ratio of Actual to Standard	*1.82*	*0.80*	*1.24*	*0.025*

Notes:

a. The LDV SULEV standard is adopted from the LEV II 120,000-mile exhaust standard.
b. All SULEV standards are for 120,000 miles.
c. A PM_{10} standard is not specified for CNG vehicles; the diesel PM_{10} standard is shown.
d. The ratio of actual to standard emissions is assumed to be the same for MDVs as it is for LDVs; the MDV standard is multiplied by this ratio to estimate actual emissions.

Table A2a. 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 (Tier1)	13.9	0	0	(b)
HC evap (TLEV, LEV, ULEV)	10.2	0	0	(c)
HC evap (SULEV)	2.55	0	0	(d)
HC evap (PZEV SULEV)	0	0	0	(d)
HC evap (HDT)	20.9	0	0	(e)
SO_x	1.6	2.6	0.037	(f)
CH_4	4.4	0.47	45.6	(f)
N_20	3.3	0.35	2.59	(f)
CO_2, g/gal	8200	9890	6250	(f)
CO_2, g/MJ	62.2	67.6	47.4	(g)

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. Delucchi gives 0.47g/mi for evaporative NMOG [H:B15] for a 29.5 MPG vehicle [C:B16], which implies the 13.9 g/gal value used here.
c. The EPA and CARB evaporative emissions standards are the same in g/test, but the CARB test is more stringent (EPA 1997). Therefore, we estimate evaporative emissions for CARB-certified gasoline vehicles by scaling the Delucchi-derived Tier 1 estimates downward by the ratio of CARB to Tier 1 estimates as given in Mobil 5a (Newell 1997): (0.28 g/mi / 0.38 g/mi)* 13.9 g/gal = 10.2 g/gal. For diesel and CNG, we assume zero evaporative emissions, as in Delucchi (1997b).
d. Gasoline vehicles with the PZEV credit are modeled with zero evaporative emissions. Evaporative emissions levels for non-PZEV gasoline SULEV vehicles are estimated 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 = 2.55 g/test). All SULEV CNG vehicles are assumed to have zero evaporative emissions.
e. HDT evaporative emissions are estimated as the product of the Tier 1 emissions estimate multiplied by the ratio of Tier 1: HDT evaporative standards (3.0 g/test : 2.0 g/test). The test procedures are the same for LDTs and HDTs.
f. Emissions estimates for CH4, N2O, 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).
g. CO_2 results are also shown in terms of a common energy unit, grams per megajoule (g/MJ). (1055 MJ = 1 MBtu).

Table A2b. 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 Table A2c on the following page.

Table A2c. 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)	56.5%	2.2%	7.1%	1.4%	18.6%	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)	Coal	Oil	Natural Gas Boiler	Natural Gas Turbine
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	2.8	0.010
CH_4	2.9	2.7	0.4	35.9	2.2	0.008
CO	35.7	47.7	59.6	164	27.8	0.095
N_2O	12.6	6.3	6.6	6.6	7.8	0.027
NO_x	964	398	511	408	595	2.031
SO_x	1073	621	0.9	0.9	620	2.114
PM_{10}	35.6	17.6	0.5	6.3	20.6	0.070
CO_2 (kg/MBtu)	300	236	176	176	190	647

Nuclear Power Externality Cost		
Damage cost (c/kWh)	0.61	(b)
Generation share	18.6%	(c)
Cost (c/kWh)	0.11	
Non-nuclear electricity cost	0.57	(d)
Overall external electricity cost c/kWh)	0.68	

Notes:

Source: Delucchi (1997b) GHG Model, Sheets D, J. DOE (1997) Electric Power Annual 1996, Vol. I, table 8.

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. From DOE (1998a). Annual Energy Outlook, Table A8, p. 112.

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

Table A3a. Emissions from Vehicle Manufacture and Assembly:
Vehicle Composition and the Energy Associated with Materials Production

Material	Content Fraction	Production Energy (Btu/lb)	Coal	Oil	*fraction of oil** *residual*	*distillate*	Natural Gas	Electricity
			------------ Fraction of Production Energy by Fuel ------------					
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)

Table A3b. 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

Table A3c. 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 Table A3b.

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.

Table A4. Summary of Fuel Properties and Greenhouse Gas Emission Factors

	Reformulated Gasoline (a)	Diesel Fuel (b)	CNG (c)	National Average Electricity (d)
Common units	gal	gal	100 scf	kWh
Density, kg/liter	0.737	0.842	0.000716	--
Energy content (HHV), Btu/unit	120,800	138,700	100,200	3,412
Higher Heating Value, MJ/kg	45.6	45.8	52.1	--
Carbon, direct content (e)	0.842	0.858	0.722	--
Direct CO_2 from combustion, g/MJ (f)	61.5	67.6	47.4	--
Direct CO_2 from combustion, g/gal	7830	9890	6250	--
CO_2-equiv from combustion, g/MJ (g)	82.4	72.3	67.4	--
Total FFC CO_2-equiv, g/MJ (h)	100.5	85.9	84.0	179.7
expressed in kg CO_2-equiv per unit	12.81	12.57	8.88	0.647
ratio of FFC to direct combustion CO_2	*1.63*	*1.27*	*1.77*	--

Notes:

The values given here were derived from the Delucchi (1997b) GHG Emissions model, version of Nov. 20, 1997; references to spreadsheet locations are in brackets [ ], estimates are for calculated scenario year 2005. The values in this table are representative estimates based on vehicles which Delucchi modeled at hypothetical fuel efficiencies, and so may not exactly match the estimates used for our ratings calculations, which were done using other Delucchi-derived parameters for particular real-world vehicle characteristics, e.g., as in Tables 4 and A2.

a. Reformulated gasoline (RFG) is about 1.4% less dense and has an energy content about 2% lower than the 125,000 Btu/gal value for conventional gasoline; from "Characteristics of Gasolines" section [E:A20-F25].
b. Properties for diesel fuel from "Fuel Characteristics" section [E:A65-K71].
c. Compressed natural gas (CNG) is measured in standard cubic feet (scf) with properties as given for pipeline natural gas at standard (atmospheric) pressure and temperature, from "Characteristics of Gases" [E: 106-133]; CNG is, of course, more dense when compressed in fuel tanks.
d. For DOE national average generating mix (see Table A2b).
e. Mass percentage of fuel that is carbon, (kg C per kg of fuel) [E:F34, H69, L127].
f. Released by combustion in motor vehicle, excluding other combustion products [H:55] (see Table A2a).
g. CO_2-equivalent GHG emissions from vehicle, counting direct CO_2 plus effects of other gases [H:C62].
h. CO_2-equivalent Full Fuel Cycle (FFC) emissions: GHG emissions from vehicle plus GHG emissions from fuel and feedstock production and distribution processes, including CO_2 plus effects of other gases.

Appendix B

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 most consumers 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 15 years ago. Today's most rapidly growing segment, 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 the Subaru Forester (classified by EPA as a Special Purpose Vehicle but being similar to a Midsize Wagon with 4-wheel drive).

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 1998b). This publication is generally released in October of the calendar year proceeding the nominal model year; for example, DOE (1998b) is the *Model Year 1999 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. We combine Midsize Station Wagons and Large Station Wagons into a single class, which we term Midsize Wagon. 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 Truck, Van and 4x4 Book* (Gillis 1998) and *Consumer Reports* (1997).

Pickups. EPA classes divide pickups into Small 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 overall width (a specification routinely reported by manufacturers). We use the roughly bimodal distribution of pickups by width to classify pickups as either Compact (Chevrolet S10, Ford Ranger and Dodge Dakota) or Standard (Chevrolet Silverado, Ford F-150, and Dodge Ram). 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 without clear distinctions. It also has separate classes for 2WD and 4WD Special Purpose Vehicles, which incorporate many models having consumer characteristics similar to passenger vans or sport utilities. In this case, we largely abandon the EPA classifications. We again use overall width 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 Truck, Van and 4x4 Book* and *Consumer Reports*, we classify it as a Minivan. EPA classifies the Chrysler Town & Country, Dodge Caravan, Ford Windstar, Chevrolet Venture and Oldsmobile Silhouette as Special Purpose Vehicles and not as vans. We classify them all as Minivans.

Sport Utility Vehicles. Most sport utility vehicles are classified by EPA as Special Purpose Vehicles (2WD or 4WD). We use a classification scheme more representative of market segments, distinguishing, for example, between vehicles such as the Chevrolet Tracker and the GMC Yukon. Again, overall width provides a good determinant. The three classes (Small, Medium, and Large) used in *The Truck, Van and 4x4 Book* appear well suited for classifying sport utility vehicles. Examples of Small Utilities include the Chevrolet Tracker, Suzuki Vitara, and Toyota RAV4. Medium Utilities include the Chevrolet Blazer and Jeep Cherokee. Large Utilities, 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 2001 light duty fleet is given in Figure 2. Table B1 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 7.

Table B1. Cutpoints Used to Determine Class Rankings for Model Year 2001 Vehicles

Vehicle Class	Class Ranking Upper Limits (EDX, ¢/mi)[a] Superior ✓	Above Average ▲	Average ○	Below Average ▽	Inferior ✖
Percentile Guideline	95% +	80%–95%	35%–80%	15%–35%	0–15%
Two Seaters	1.50	1.95	2.30	2.65	>2.65
Subcompacts	1.42	1.85	2.16	2.38	>2.38
Compacts	1.50	1.69	2.03	2.16	>2.16
Midsize Cars	1.79	2.03	2.30	2.38	>2.38
Large Cars	2.03	2.15	2.30	2.45	>2.45
Small Wagons	1.64	1.75	2.10	2.30	>2.30
Large Wagons	1.70	1.85	2.22	2.30	>2.30
Compact Pickups	2.07	2.24	2.73	2.84	>2.84
Standard Pickups	2.42	2.82	3.17	3.50	>3.50
Small Utilities	1.85	1.99	2.29	2.47	>2.47
Medium Utilities	2.37	2.54	2.83	3.05	>3.05
Large Utilities	2.42	3.29	3.60	3.76	>3.76
Minivans	2.31	2.45	2.62	2.80	>2.80
Large Vans	2.45	3.05	3.30	3.55	>3.55

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 2001 average of 23 (corresponding to the MY2001 combined car-truck average EDX of 2.42¢\mi).

Appendix C

SUMMARY OF REVISIONS FOR 2001

Only a few changes and additions to our environmental rating methodology were made in updating the 2000 edition (DeCicco and Kliesch 2000) for application in *ACEEE's Green Book™: The Environmental Guide to Cars and Trucks – Model Year 2001*. The methodological framework used for MY2001 is the same as was used for MY2000, but we modified some assumptions and numerical parameters based on reviewer comments and analysis of new data. Key changes for 2001 include:

- Revised tailpipe emissions estimates for gasoline vehicles, based on introduction of the Supplemental Federal Test Procedure (SFTP).
- Updated estimates of lifetime average sulfur content of gasoline.
- Handling Unique tailpipe emission estimates for vehicles receiving the zero-evaporative emission partial-ZEV (PZEV) credit.

SUPPLEMENTAL FEDERAL TEST PROCEDURE

Incorporating the Model Year 2001 introduction of the Supplemental Federal Test Procedure (SFTP) into our methodology was the most critical change for this year's analysis, since its incorporation necessitated modest reductions in our in-use tailpipe emission factors (Federal Register 1996). Although the SFTP program will follow a legislated phase-in schedule, it is not be practical for *ACEEE's Green Book™* to identify specifically which vehicles are SFTP-compliant and which are not. Therefore, all MY2001 vehicles were treated as SFTP-compliant. The EPA emissions modeling tool currently used in our analysis (Koupal 1999) incorporates SFTP functionality, reflecting reductions of HC and NO_x in-use emissions expected by control improvements motivated by the SFTP.

As stated earlier in this report, SFTP-related reductions in CO emissions estimates were determined in consultation with members of EPA's MOBILE 6 modeling staff (Koupal 2000). Based on these consultations, last year's off-cycle CO estimates were adjusted to yield new, SFTP-based off-cycle estimates that accounted for both control improvement-related emissions reductions, and a modest CO increase due to air conditioning loading. Overall, these adjustments produce a 17-25% drop from Model Year 2000 CO estimates for Tier 1 vehicles, and a 20-28% drop for LEV vehicles, depending on vehicle class.

The SFTP final rule provided only a US06 off-cycle control requirement for LDV and LDT1 diesel vehicles, and exempted LDT2-4 light truck diesels for lack of data. The SFTP final rule also exempted diesels from the supplemental air conditioning test. While recognizing the large uncertainty regarding light duty diesel in-use emissions, the absence of data suggests caution. Therefore, we left all diesel emissions factors unchanged from our MY2000 estimates, which remain based on EPA analytic work supporting the development of MOBILE 6.

GASOLINE SULFUR

Our approach for incorporating the effect of gasoline sulfur content in our emission factors remains intact for Model Year 2001. Emission factors for California-certified gasoline vehicles are determined using a lifetime average sulfur level of gasoline from California, New York, Massachusetts, Vermont, and Maine, while emission factors for federally-certified gasoline vehicles are computed using an estimated lifetime average sulfur level of the remaining states. Since our methodological approach for handling gasoline sulfur remains intact, the only change necessary was updating the time window for measuring lifetime average sulfur levels. This update reduced the lifetime average "federally-certified" sulfur level from 100 ppm (in MY2000) to 80 ppm. The list of LEV-mandated states grew from four to five (with the addition of Maine) for MY2001, and the lifetime average sulfur level of these states changed from 40 ppm to 30 ppm. The results are shown below.

Estimated Lifetime Average Gasoline Sulfur Levels for MY2000 and 2001 Vehicles

Region	MY2000 Sulfur Level (ppm)	MY2001 Sulfur Level (ppm)
National Average	90	70
LEV-Mandate States	40	30
Remaining 46 States	100	80

HANDLING ZERO-EVAPORATIVE EMISSIONS GASOLINE VEHICLES

This year, with respect to evaporative hydrocarbon emissions, we differentiate between gasoline vehicles meeting the SULEV emissions standard, and SULEV-certified gasoline vehicles with the zero-evaporative emissions PZEV credit. (In accordance with last year's methodology, CNG vehicles continue to be modeled with no evaporative hydrocarbon emissions.)

In MY2000, we considered all gasoline SULEV-certified vehicles as zero-evaporative emissions vehicles; this year gasoline vehicles with the PZEV credit are modeled with zero evaporative emissions, while non-PZEV gasoline SULEV vehicles are modeled with a minor amount of evaporative emissions. The estimation for the latter 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 Table A2a.

REFERENCES

AAMA. 1997. *Summer Gasoline Sulfur Survey.* Washington, DC: American Automobile Manufacturers' Association.

An, F. and M. Ross. 1993. *A Model of Fuel Economy and Driving Patterns.* SAE Paper 930328. Warrendale, PA: Society of Automotive Engineers.

Automotive News. 1999. Production data provided during conversation with Automotive News Data Department. September 2.

Babcock and Wilcox. 1978. *Steam, Its Generation and Use, 39th ed.* New York, NY: The Babcock and Wilcox Company.

Calvert, J.G., J.B. Heywood, R.F. Sawyer, and J.H. Seinfeld. 1993. "Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions." *Science* 261: 37-45, July 2.

CARB. 1996. *California Motor Vehicle Emission Control and Smog Index Label Specifications.* Sacramento, CA: California Air Resource Board.

———. 1997. *Proposed Amendments to California's Low-Emission Vehicle Regulations: LEV-II.* November 7 Draft Preliminary Staff Report. Sacramento, CA: California Air Resources Board, Mobile Sources Control Division.

Consumer Reports. 1997. Annual Auto Issue. *Consumer Reports.* April.

DeCicco, J., and J. Kliesch. 2000. *Rating the Environmental Impacts of Motor Vehicles: The Green Guide to Cars and Trucks Methodology, 2000 Edition.* Washington, DC: American Council for an Energy-Efficient Economy.

———. 2001. *ACEEE's Green Book™: The Environmental Guide to Cars and Trucks — Model Year 2001.* Washington, DC: American Council for an Energy-Efficient Economy.

DeCicco, J., and M. Thomas. 1999a. *Rating the Environmental Impacts of Motor Vehicles: The Green Guide to Cars and Trucks Methodology, 1999 Edition.* Washington, DC: American Council for an Energy-Efficient Economy.

———. 1999b. "A Method for Green Rating of Automobiles." *Journal of Industrial Ecology* 3(1): 55-75.

Delucchi, M.A. 1997a. *The Annualized Social Cost of Motor-Vehicle Use in the United States, 1990–1991: Summary of Theory, Data, Methods, and Results.* UCD-ITS-RR96-3(1). Davis, CA: University of California, Institute of Transportation Studies.

———. 1997b. GHG (Greenhouse Gas) Emissions Model. Computer Spreadsheet. Davis, CA: University of California, Institute of Transportation Studies.

Delucchi, M.A., and D.R. McCubbin. 1996. *The Contribution of Motor Vehicles and Other Sources to Ambient Air Pollution.* UCD-ITS-RR96-3(16). Davis, CA: University of California, Institute of Transportation Studies.

DeLuchi, M.A. 1991. *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity.* ANL/ESD/TM 22. Argonne, IL: Argonne National Laboratory, Center for Transportation Research.

DOE. 1991. *Manufacturing Energy Consumption Survey: 1991.* Washington, DC: U.S. Department of Energy, Energy Information Administration.

———. 1995. *Electric Power Annual 1994, Volume 2.* DOE/EIA-0348(94)/2. Washington, DC: U.S. Department of Energy, Energy Information Administration.

———. 1997. *Electric Power Annual 1997, Volume I.* DOE/EIA-0348(97/1). Washington, DC: U.S. Department of Energy, Energy Information Administration.

———. 1998a. *Annual Energy Outlook 1998.* DOE/EIA-0383(98). Washington, DC: U.S. Department of Energy, Energy Information Administration.

———. 1998b *Model Year 1999 Fuel Economy Guide.* Washington, DC: U.S. Department of Energy.

———. 1999. *Annual Energy Outlook 1999.* DOE/EIA-0383(99). Washington, DC: U.S. Department of Energy, Energy Information Administration.

DOT. 1998. *Highway Statistics 1997.* FHWA-PL-98-020. Washington, DC: U.S. Department of Transportation, Federal Highway Administration.

Duleep, K.G. 1997. "The Potential for Evolutionary and Revolutionary Technologies to Improve Automotive Fuel Economy." Chapter 7 in J. DeCicco and M. Delucchi (eds.), *Transportation, Energy, and the Environment: How Far Can Technology Take Us?* Washington, DC: American Council for an Energy-Efficient Economy.

Durbin, T., M. Smith, M., J. Norbeck, and T. Truex. 1997. Population Density, Particulate Emission Characterization, and Impact on the Particulate Inventory of Smoking Vehicles in the South Coast Air Quality Management District. Accepted for publication in J. Air and Waste Manage. Assoc.

Energy Innovations. 1997. *Energy Innovations: A Prosperous Path to a Clean Environment.* Washington, DC: Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists.

EPA. 1993a. *Status Report on the Use of Environmental Labels Worldwide.* EPA 742-R-93-001. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics.

———. 1993b. *The Use of Life Cycle Assessment in Environmental Labeling.* EPA 742-R-93-003. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics.

———. 1996. Mobile 5a Emissions Model. Ann Arbor, MI: U.S. Environmental Protection Agency, Office of Mobile Sources.

———. 1997. Test Car List. Database. Ann Arbor, MI: U.S. Environmental Protection Agency.

———. 1998. *1996 Toxics Release Inventory Public Data Release — Ten Years of Right-to-Know: Industry Sector Analyses.* EPA 745-R-98-018. Washington, DC: U.S. Environmental Protection Agency.

———. 1999a. *Determination of CO Basic Emission Rates, OBD and I/M Effects for Tier 1 and Later LDVs and LDTs (Draft).* EPA 420-P-99-017. Ann Arbor, MI: U.S. Environmental Protection Agency.

———. 1999b. *Regulatory Impact Analysis. Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (Draft).* EPA420-D-99-001. Ann Arbor, MI: U.S. Environmental Protection Agency.

———. 1999c. *Basic Exhaust Emission Rates of Open Loop Vehicles for MOBILE 6 (Draft).* EPA 4290-P-99-020. Ann Arbor, MI: U.S. Environmental Protection Agency.

Federal Register. 1996. "Final Rule on the Supplemental Federal Test Procedure." 61 (205): 54871-54872.

———. 2000. "Control of Air Pollution from Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule." 65 (28).

FTC. 1996. *Labeling Alternative Fueled Vehicles: A Guide for Manufacturers, Conversion Companies, and Retailers of Alternative Fueled Vehicles.* Washington, DC: Federal Trade Commission, Bureau of Consumer Protection.

Gillis, J. 1998. *The Truck, Van and 4x4 Book: 1998 Edition.* New York, NY: Harper Collins.

Heavenrich, R.M., and K.H. Hellman. 2000. *Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2000.* EPA420-R-00-008. Washington, DC: U.S. Environmental Protection Agency, Office of Transportation and Air Quality.

Hwang, R. 1997. *Are Cars Still a Problem? Real-World Emission Reductions from Passenger Vehicles over the Past 30 Years.* Berkeley, CA: Union of Concerned Scientists.

IPCC. 1995. *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, England: Cambridge University Press.

Keoleian, G.A., K. Kar, M.M. Manion, and J.W. Bulkley. 1997. *Industrial Ecology of the Automobile: A Lifecycle Perspective.* Warrendale, PA: Society of Automotive Engineers.

Koupal, J. 1999. "Tier1FER.xls," Microsoft Excel spreadsheet model. Personal communication to authors. Ann Arbor, MI: U.S. Environmental Protection Agency.

Koupal, J. 2000. Personal communication to authors. Ann Arbor, MI: U.S. Environmental Protection Agency.

Lovins, A. 1995. "Hypercars: The Next Industrial Revolution." Chapter 5 in D. Sperling and S.A. Shaheen (eds.), *Transportation and Energy: Strategies for a Sustainable Transportation System.* Washington, DC: American Council for an Energy-Efficient Economy.

Mark, J. and C. Morey. 1999. *Diesel Passenger Vehicles and the Environment.* Berkeley, CA: Union of Concerned Scientists.

Mintz, M.M., A.R.D. Vyas, and L.A. Conley. 1993. *Differences between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?* 931104. Washington, DC: Transportation Research Board.

Newell, Terry. (Office of Mobile Sources, National Vehicle Fuel and Emissions Laboratory) 1997. Personal communication to Martin Thomas. September 4.

ORNL. 1997. *Transportation Energy Databook, Edition 17.* ORNL-1919. Oak Ridge, TN: Oak Ridge National Laboratory.

Ottinger, R.L. (ed.). 1991. *Environmental Costs of Electricity.* Prepared by the Pace University Center for Environmental Legal Studies. New York: Oceana Publications.

PNGV. 1994. *Partnership for a New Generation of Vehicles, Program Plan.* Washington, DC: U.S. Department of Commerce.

Ross, M., R. Goodwin, R. Watkins, M.Q. Wang, and T. Wenzel. 1995. *Real-World Emissions from Model Year 1993, 2000 and 2010 Passenger Cars.* Report prepared for The Energy Foundation. Washington, DC: American Council for an Energy Efficient Economy.

Ross, M. and T. Wenzel. 1998. "Lifetime Emissions Due to Malfunction of Emissions Controls." Presented at the Transportation Research Board Workshop on Air Quality Impacts of Conventional and Alternative Fuel Vehicles, Ann Arbor, MI, August 2-4.

Wang, M.Q. 1996. *Development and Use of the GREET Model to Estimate Fuel Cycle Energy Use and Emissions of Various Transportation Technologies and Fuels.* ANL/ESD-31. Argonne, IL: Argonne National Laboratory, Center for Transportation Research.

———. 1999. GREET v. 1.5 Fuel Use and Emissions Model. Computer Spreadsheet. Argonne, IL: Argonne National Laboratory, Center for Transportation Research.

Wang, M.Q., and D.J. Santini. 1995. "Monetary Values of Air Pollutant Emissions in Various U.S. Regions." *Transportation Research Record* 1475: 33-41.

Weaver, C. and L. Chan. 1997. *Comparison of Off-Cycle and Cold-Start Emissions from Dedicated NGVs and Gasoline Vehicles.* GRI-96/0217. Chicago, IL: Gas Research Institute.