United States Environmental Protection Agency | Air and Radiation | EPA420-P-02-005
August 2002
M6.GHG.001

Updating Fuel Economy Estimates in MOBILE6.3

DRAFT

EPA420-P-02-005
August 2002

Updating Fuel Economy Estimates in MOBILE6.3

DRAFT

M6.GHG.001

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

ABSTRACT

In the previous versions of EPA's MOBILE model, estimates of fleet fuel economy (by model year and by vehicle class) were used to help predict refueling losses from gasoline-fueled vehicles and trucks. The use of these fuel economy estimates was expanded to help predict particulate emissions from diesel-fueled vehicles in MOBILE6.1.

In this report, EPA proposes to update those fuel economy estimates. These updated estimates will then be used to predict CO_2 emissions. These updated estimates will still vary only by model year and vehicle class.

****

Please note that EPA is seeking any input from stakeholders and reviewers that might aid us in modeling any aspect of fuel consumption.

Comments on this report and its proposed use in MOBILE6.3 should be sent to the attention of Larry Landman. Comments may be submitted electronically to mobile@epa.gov, or by fax to (734) 214-4939, or by mail to "MOBILE6 Review Comments", US EPA Assessment and Standards Division, 2000 Traverwood Drive, Ann Arbor, MI 48105. Electronic submission of comments is preferred. In your comments, please note clearly the document that you are commenting on, including the report title and the code number listed. Please be sure to include your name, address, affiliation, and any other pertinent information.

This document is being posted on the MOBILE6 website. The release of this report will be announced via the MOBILE listserver. Comments will be accepted for sixty (60) days from the date this report is released. EPA will then review and consider all comments received and will provide a summary of those comments, and how we are responding to them.

*** **DRAFT** ***

Updating Fuel Economy Estimates in MOBILE6

Report Number M6.GHG.001

Larry C. Landman
U.S. EPA Assessment and Standards Division

1.0 INTRODUCTION

In recent years, there has been an increased interest in modeling the emissions of green house gasses (GHG) from mobile sources. The Assessment and Standards Division is undertaking two projects to address the needs for a "bottom-up" Mobile Sources GHG model: a new generation model and an "interim" model which we are calling "MOBILE6.3" because it is be based on MOBILE6.

The New Generation GHG model will estimate all four major mobile source greenhouse gasses: carbon dioxide (CO_2), air conditioning refrigerants, nitrous oxide (N_2O), and methane (CH_4). It will calculate inventories (which is currently performed as an extra step outside of MOBILE). Its estimates are likely to take into account additional factors such as vehicle speed, effects of inspection maintenance programs, extent of air conditioning usage, ambient temperature, roadway types, roadway grades, and vehicle weight (including load) to the extent that those factors are found to be significant.

While work is proceeding on this New Generation GHG model, EPA is also working on a less sophisticated approach to serve as an interim model. This interim model, MOBILE6.3, will be based on MOBILE6. MOBILE6.3 will add the ability to estimate CO_2 emissions to the MOBILE model in a simple fashion. Vehicle fuel economy estimates already in the model, based on vehicle class and model year, will be updated. We will also add an option for the user to input these rates, e.g. to model alternative assumptions about future vehicle fuel economy performance. CO_2 emission rates will then be calculated from these fuel consumption values by assuming that all the carbon in the fuel that is not emitted as HC or CO, is emitted as CO_2.*****

***** EPA calculates fuel consumption (gallons per mile) as a linear combination of HC, CO, and CO_2 (see **40 CFR 600.113**). Therefore, any one of those four values (i.e., CO_2) can be calculated given the remaining three.

Previous versions of the MOBILE model have contained estimates of fuel economy (by model year and by vehicle class). Those estimates were used to predict refueling losses from gasoline-fueled vehicles and trucks and, beginning in MOBILE6.1, to help estimate sulfate particulate emissions.

MOBILE fuel economy estimates have not been revised in recent years (at least for the gasoline-fueled vehicles and trucks) and are poorly documented.

In this report, EPA proposes new, updated estimates for fuel economy for each of the 28 vehicle classes and for each model year. The 28 vehicle classes used in MOBILE6 are listed in Appendix A. Although fuel economy is known to be affected by a variety of factors, the estimates of fuel economy in MOBILE6.3 (like those in the earlier versions of MOBILE) will depend only on vehicle type and model year. Hence, it will not be appropriate to use MOBILE6.3 for tasks estimating the CO_2 effects of changing speed limits or the presence of an I/M program. Instead, EPA intends for MOBILE6.3 to be used to model large scale (e.g., national annual) modeling domains for which CO_2 variations due to variations in factors such as vehicle speed and ambient temperatures can reasonably be expected to "average out."

2.0 DATA SOURCES

The data on in-use fuel economy values (by model year and vehicle class) were obtained primarily from the following sources:

(1) "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 Through 2001" **[1]** as well as an earlier version of that report "Light-Duty Automotive Technology and Fuel Economy Trends Through 1989." **[2]**

(2) "Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6: Analysis of Fuel Economy, Non-Engine Fuel Economy Improvements, and Fuel Densities," **[3]** and

(3) "National Transportation Statistics 2000." **[4]** Used for estimating motorcycle fuel economy.

Complete references for these reports are contained in Section 5 of this report.

2.1 Fuel Economy of Passenger Cars and Light-Duty Trucks

At the end of each model year, EPA calculates a corporate average fuel economy (CAFE) for each manufacturer. For decades, EPA has analyzed the data that were used to calculate these

CAFEs. The results of these analyses were published in a series of annual "trends reports." (The analyses in those reports do not include various credits that are part of each manufacturer's official CAFE.) The most recent of those analyses is the report entitled "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 Through 2001." **[1]**

The fuel economy values in that report are based on laboratory data, specifically the Federal Test Procedure (FTP) and the Highway Fuel Economy Test (HFET). The Department of Transportation (DOT) uses a composite of these fuel economy values (i.e., the weighted harmonic average of the FTP and HFET) to determine compliance with the CAFE standards.

However, EPA has found that the actual in-use fuel economy falls short of that composite value. Therefore, to more closely approximate real world fuel economy, the EPA has for several programs (e.g., on new vehicle labels, in the EPA/DOE Fuel Economy Guide, and in EPA's Green Vehicle Guide) adjusted these laboratory results. The multiplicative adjustment factor for the city (FTP) fuel economy is 0.90 and for the highway (HFET) fuel economy is 0.78 (see **40 CFR 600.209-95**). Weighting these adjusted FTP and HFET results produces an "adjusted" composite result that is about 0.85 times the composite result used in the CAFE program. These adjusted composite results are the values used in both the most recent "trends report" **[1]** and in this report.*

In Appendices B and C, we have reproduced passenger car and light-truck fuel economies (respectively) from the first table of the most recent "trends report." **[1]** EPA believes that these "adjusted" composite fuel economy values are most appropriate estimates of the real world passenger car and light truck fuel economies for each model year (from 1975 through 2001) to use for MOBILE6.3. The basic assumption here is that average fuel economy does not change as the vehicles age.

2.1.1 Separating Light-Duty Diesel-Fueled from Gasoline-Fueled

It is necessary to separate the gasoline-fueled vehicles from the corresponding diesel-fueled vehicles for two reasons. First, the equation to calculate CO_2 emissions for the gasoline-fueled vehicles is different from the one used for diesel-fueled vehicles. Second, the fuel economy values of the diesel-fueled vehicles are usually higher than the fuel economy values of the corresponding gasoline-fueled vehicles.

---

* A recent analysis **[5]** of the results of the Residential Transportation Energy Consumption Survey (a 1985 survey of car owners conducted by the Energy Information Administration of the US DOE) indicates that the shortfall may be larger than those EPA adjustment factors. However, since we do not have any adjustment factors superior to the current ones, we will use them in this analysis.

Appendices B and C categorize the light-duty portion of the fleet as passenger cars and light trucks; however, in MOBILE6, the passenger cars (LDVs) and light trucks (LDTs) are divided into gasoline-fueled and diesel-fueled classes, and the light-duty trucks are further divided into four weight classes (Appendix A). Unfortunately, the recent "trends report" **[1]** does not provide that additional break down. Separate calculations for gasoline and diesel were dropped when the penetration of diesel-fueled vehicles decreased to a point where their effect on the fleet average fuel economy was not considered significant.

However, the earlier version of the "trends report" **[2]** does have separate calculations of the fuel economies of the gasoline-fueled and the diesel-fueled fleets. In Appendix E, we compiled data from Tables 6 and 7 of an earlier version of the "trends report" **[2]**. This stratification of fuel economies by fuel type was limited to the 1978-1989 model year range. In Appendix F, we "adjusted" those values and combined them with the values from Appendices B and C. The diesel sales fractions used for these calculations come from MOBILE6 **[6]**, and are reproduced in Appendix D. After examining the fuel economies in Appendix F, we observe:

(1) As expected, the fuel economies of the gasoline-fueled vehicles match the corresponding values for the combined (gasoline plus diesel) vehicles for the newest model years due to the small percentage of diesels in the fleet for these model years.

(2) While the fuel economies of the gasoline-fueled vehicles (both cars and trucks) are a relatively smooth function of model year, the fuel economies of the diesel-fueled vehicles have substantial year-to-year fluctuations. This is a manifestation of their small sales volume. The low sales of light-duty diesel passenger cars allow one or two diesel engines to dominate sales for particular model years (often different engines for different years).

While the fleet fuel economies for LDVs and LDTs in Appendices B and C (and hence Appendix F) are calculated for each model year from 1975 through 2001, the separation by fuel type (Appendix E) is limited to the 12 model years from 1978 through 1989. To expand these estimates to the larger range of model years, EPA made the following assumptions based on observations of the values in Appendix E:

(3) The fleet fuel economies (by model year) of the light-duty gasoline vehicles (LDGVs) was 0.1 or 0.2 miles per gallon (mpg) lower than the corresponding combined values. The difference tended to be 0.2 for the model years with the largest diesel penetrations and 0.1 for the years with the smallest diesel penetrations.

Thus, EPA proposes to set the 15 missing fuel economies (in Appendix F) for the LDGVs to be 0.1 mpg less than the corresponding values for the LDVs (i.e., combined).

(4) The fuel economy of the 1978 and 1979 model year light-duty diesel vehicles (LDDVs) averaged 24.0 mpg. EPA proposes to estimate the fuel economies of the 1975-77 model year LDDVs as also 24.0.

Similarly, the fuel economy of the 1986-89 model year LDDVs averaged 32.4 mpg. EPA proposes to estimate the fuel economies of the 1990-2001 model year LDDVs as also 32.4.

(5) Among the 1986-89 model year LDTs, the penetration of diesels is comparable to the 1990-2001 model years. In the 1986-89 model years, the fleet fuel economies (by model year) of the light-duty gasoline trucks (LDGTs) averaged about 0.1 mpg lower than the corresponding combined values. Thus, EPA proposes to set the 12 missing fuel economies (in Appendix F) for the LDGTs in model years 1990-2001 to be 0.1 mpg less than the corresponding values for the LDTs.

(6) For the 1986-89 model years, the fuel economies of the light-duty diesel trucks (LDDTs) averaged 20.6 mpg. EPA proposes to set the fuel economies for the 1990-2001 model year LDDTs equal to the same value.

(7) The diesel penetration in the LDTs for the 1976-77 model years is comparable to the penetration during the 1978-79 model years. During the 1978-79 model years, the fuel economies of the LDGTs was within 0.1 mpg of the corresponding values of the LDTs. Hence, EPA proposes to set the fuel economies of the 1976-77 model year LDGTs to be 0.1 mpg less that the corresponding LDTs.

The diesel penetration for the 1975 LDTs was comparable to that of the 1981-82 model years. During those two model years, the fuel economies of the LDGTs was about 0.4 mpg less than the corresponding values of the LDTs. Hence, EPA proposes to set the fuel economy of the 1975 model year LDGTs to be 0.4 mpg less that the corresponding LDTs (i.e., 11.2 mpg)

(8) The fuel economies of the 1978-79 LDDTs averaged 18.0 mpg. EPA proposes to set the fuel economies of the 1975-77 LDDTs equal to that value.

Using the proposals in these preceding points numbered 3 through 8, EPA developed estimates for the 60 values missing from Appendix F. Inserting those values into Appendix F produces Appendix G.

2.1.2 Separating Light-Duty Trucks by Weight Classes

None of the "trends reports" distinguishes the LDT fuel economies by the weight classes in Appendix A. However, we can calculate those values from Appendix G if we know:

(1) the relative number of trucks in each of the weight classes and

(2) the fuel economy ratios by model year (i.e., the LDT12 fuel economy divided by the fuel economy of the corresponding LDT34).

In MOBILE6*****, the LDT12 comprise, on average, about three-fourths of all of the LDTs **[6]**.

We can estimate those ratios of light-duty fuel economy (by model year) by making use of a well known fact, namely, that the test weight of the vehicle is one of the major factors in predicting its fuel economy (in dynamometer testing). However, the distinguishing characteristic between the LDT12 and the LDT34 is the gross vehicle weight rating (GVWR), not the test weight (or even the curb weight).****** (The GVWR of the LDT12 is 6,000 pounds and lighter, and the GVWR of the LDT34 is from 6,001 up through 8,500 pounds.) However, the GVWR does not correlate perfectly with either the vehicle test weight or the curb weight.

We do not have the average test weights of these two truck classes on a national basis. However, examining the test weights of the trucks in the Mobile Source Observational Data Base (formerly the Emission Factors Data Base) **[7]**, we note that the mean test weight of those LDT12 trucks was 3,607 pounds, while the mean test weight of those LDT34 trucks was 4,539 pounds.

Then, in Table 14 of the earlier trends report **[2]**, the average fuel economy is calculated for each light-duty truck test weight class for each model year (from 1978 through 1989). While the fuel economies vary by model year, the ratios of the fuel economy of the 3,500 pound test weight class divided by the corresponding fuel economy of the 4,500 pound test weight class ranges between 1.165 and 1.403, with a mean value of 1.3045. (If we were to use the data in that table to first estimate, by interpolation, the fuel economies that would be associated with

---

***** In MOBILE6 (see References 6, Table 4), for the 1975-96 model years, the ratio of the number of LDT12s to the number of all LDT ranged between 52.1 percent and 79.5 percent (with an average of 75.13 percent). For the purpose of these estimates, we will use a constant ratio of three-fourths.

****** The "curb weight" is the actual weight of the vehicle in operational status with all standard equipment and weight of fuel at nominal tank capacity. The "gross vehicle weight rating" (GVWR) is a value defined by the vehicle manufacturer which includes the total weight of the vehicle plus the weight of the fluids, driver and the maximum recommended payload.

3,607 and 4,539 test weights, and then calculate those fuel economy ratios. We obtain ratios that range between 1.173 and 1.362, with a mean value of 1.2830. Alternatively, rather than using interpolation, a third approach to estimating the fuel economies associated with 3,607 and 4,539 test weights would be to assume that the ton-miles per gallon is relatively constant in the range of each of those two test weights. This third approach yields ratios that range between 1.241 and 1.420, with a mean value of 1.3403.) Each of those three approaches reaches the same conclusion, the ratio of the fuel economy of the LDT12 to the fuel economy of the LDT34 (for each model year) is about 1.3.

Applying that fuel economy ratio of 1.3 for LDTs to the values in Appendix G allows us to estimate the fleet fuel economies (by model year) for the LDT12 and LDT34 classes. The results of those calculations are given in Appendix H.

To check these values (in Appendix H) for reasonableness, we note that the predicted fuel economies of the passenger cars are higher than the fuel economies of the LDT12 which are themselves higher than the fuel economies of the LDT34. Comparing values in Appendix H to the values in Tables 2 and 3 (Section 2.2), we observe that the fuel economies of the LDT34 are higher than the fuel economies of the heavy-duty trucks. Thus, these predictions appear to be internally consistent.

2.2 Analysis of Heavy-Duty Fuel Economy

The major source of fuel economy estimates for heavy-duty vehicles is an analysis prepared for EPA by ARCADIS Geraghty & Miller, Inc. **[3]** of survey data (summarized in Appendix I) from the 1992 Truck Inventory and Use Survey (TIUS). (That survey has since been renamed the "Vehicle Inventory and Use Survey," i.e., "VIUS.") In that report, ARCADIS developed equations to predict the fuel economy for each class of heavy-duty vehicles for a limited range of model years.

In particular, fuel economy data from 59,046 heavy-duty vehicles (other than buses) from model years 1983 through 1992 were used to predict heavy-duty fuel economy for four years into the future (i.e., model years 1993 through 1996). The report does not discuss how to estimate fuel economies for model years earlier than 1983 nor for model years after 1996.

Since actual in-use fuel consumption data (rather than dynamometer test results) were used in this analysis, no adjustment factors were required (unlike the light-duty analyses in Section 2.1).

For each class of heavy-duty vehicles, the regression analyses modeled the logarithm of the average fuel economy (for each vehicle class in Appendix I) as a linear function of the logarithm of the model year. That is:

$$\text{LN(Fuel Economy)} = A + (B * \text{LN(Model Year} - 1900))$$

where "**A**" and "**B**" are given in Table 1 (below).

Table 1

Coefficients for Modeling Heavy-Duty In-Use Fuel Economy

	Gasoline-Fueled		Diesel-Fueled	
Class	**A**	**B**	**A**	**B**
HDV2b	0.1253	0.9624	0.1072	1.0506
HDV3	0.1157	0.9632	0.0989	1.0450
HDV4	0.0409	1.1902	0.5020	0.6598
HDV5	0.4416	0.6348	0.2474	0.8078
HDV6	0.0338	1.2015	0.5336	0.6117
HDV7	0.1277	0.8909	4.0206	0.1374
HDV8a	0.0647	1.0285	0.15485	0.8194
HDV8b	---	---	0.0119	1.3742

Using the coefficients from Table 1, we then calculated the estimated fuel economy for each of 15 heavy-duty vehicle classes for 14 model years from 1983 through 1996. Those 210 values are reproduced in the following tables (Tables 2 and 3). These values duplicate the corresponding values (from Tables 12 and 14 in the ARCADIS report) for model years 1987 through 1996. (The contractor was not asked to include model years prior to 1987 in its tables.)

In Table 1, no equation was provided to estimate the fuel economy of the HDGV8B trucks.***** EPA proposes estimating the fuel economies of that missing class by examining the fuel economies of the diesel-fueled trucks (in Table 3). In Table 3, we can calculate the ratio of the fuel economies of the class 8B trucks to the 8A trucks (i.e., HDD8B / HDD8A) for each model year. EPA proposes to multiply the estimated fuel economies of the gasoline-fueled 8A trucks by those ratios.

***** Those class HDGV8b trucks are rare or non-existent, and MOBILE6 estimates a population of zero for them. However, some fuel economy estimate is required for completeness.

Table 2

Projected Gasoline Heavy-Duty Vehicle Fuel Economies (mpg)

Model Year	Weight Classes: 2b	3	4	5	6	7	8A	8B
83	8.81	8.16	7.87	7.30	6.83	6.54	6.09	5.43
84	8.91	8.26	7.98	7.35	6.93	6.62	6.17	5.55
85	9.01	8.35	8.09	7.41	7.03	6.69	6.24	5.64
86	9.11	8.45	8.21	7.47	7.13	6.76	6.32	5.75
87	9.22	8.54	8.32	7.52	7.23	6.83	6.39	5.91
88	9.32	8.63	8.43	7.58	7.33	6.89	6.47	6.00
89	9.42	8.73	8.55	7.63	7.43	6.96	6.54	6.09
90	9.52	8.82	8.66	7.68	7.53	7.03	6.62	6.19
91	9.62	8.92	8.78	7.74	7.63	7.10	6.70	6.29
92	9.73	9.01	8.89	7.79	7.73	7.17	6.77	6.38
93	9.83	9.11	9.01	7.85	7.84	7.24	6.85	6.47
94	9.93	9.20	9.12	7.90	7.94	7.31	6.92	6.57
95	10.03	9.30	9.24	7.95	8.04	7.38	7.00	6.67
96	10.13	9.39	9.35	8.01	8.14	7.45	7.07	6.76

Table 3

Projected Diesel Heavy-Duty Vehicle Fuel Economies (mpg)

Model Year	Weight Classes: 2b	3	4	5	6	7	8A	8B
83	11.13	10.01	9.27	8.78	7.96	7.38	5.79	5.16
84	11.27	10.14	9.34	8.87	8.02	7.39	5.84	5.25
85	11.41	10.27	9.41	8.95	8.08	7.40	5.90	5.33
86	11.55	10.39	9.49	9.04	8.14	7.41	5.96	5.42
87	11.69	10.52	9.56	9.12	8.20	7.43	5.96	5.51
88	11.83	10.65	9.63	9.21	8.25	7.44	6.03	5.59
89	11.97	10.77	9.70	9.29	8.31	7.45	6.10	5.68
90	12.11	10.90	9.77	9.38	8.37	7.46	6.17	5.77
91	12.26	11.03	9.85	9.46	8.42	7.47	6.24	5.86
92	12.40	11.15	9.92	9.54	8.48	7.48	6.31	5.95
93	12.54	11.28	9.99	9.63	8.54	7.49	6.38	6.03
94	12.68	11.41	10.06	9.71	8.59	7.51	6.45	6.12
95	12.82	11.53	10.13	9.80	8.65	7.52	6.52	6.21
96	12.96	11.66	10.20	9.88	8.71	7.53	6.59	6.30

Also, there has been litigation concerning the effects of off-cycle operations of some heavy-duty diesel trucks (classes 3 through 8b) on NO_X emissions. The question is whether there was also an effect on fuel economy. An EPA analysis of the phase-in of these vehicles suggests the effect (if any) on fuel economy would be small until 1992; therefore, we expect little if any effect on the regression equations.

Most (but not all) of the values in Tables 2 and 3 follow these expected patterns:

- -- Fuel economy tends to decrease as weight increases.
- -- Fuel economy tends to improve with the newer vehicles.
- -- Diesel-fueled vehicles tend to achieve higher fuel economy than their gasoline-fueled counterparts.

Since the values in Tables 2 and 3 are simply smoothed regressions of the TIUS (raw) results, it is not surprising that they would follow these expected patterns. However, the raw results in Appendix I (i.e., summaries of the actual TIUS results on which the regressions were based) also follow these expected trends.

The contractor performed similar analyses on a (different) data set of fuel economies of various types of bus. Reproducing Table 15 from that contractor report, yields the following table of bus fuel economies (for model years 1987 through 1996).

Table 4

Estimated Bus Fuel Economies (mpg)

Model	<=== Diesel-Fueled ===>			<=== Gasoline-Fueled ===>		
Year	Transit	Intercity	School	Transit	Intercity	School
1987	3.43	4.64	6.29	3.11	3.64	6.18
1988	3.47	4.69	6.28	3.15	3.68	6.21
1989	3.51	4.75	6.27	3.19	3.72	6.24
1990	3.55	4.80	6.25	3.22	3.76	6.27
1991	3.59	4.85	6.24	3.26	3.80	6.30
1992	3.63	4.91	6.23	3.30	3.85	6.33
1993	3.67	4.96	6.22	3.33	3.89	6.37
1994	3.71	5.01	6.20	3.37	3.93	6.40
1995	3.75	5.07	6.19	3.40	3.97	6.42
1996	3.79	5.12	6.18	3.44	4.01	6.45

However, the six classes in Table 4 (above) do not exactly match the bus classes in MOBILE6. In MOBILE6 (see Appendix A), there are only three bus classes:

-- HDGB (all gasoline-fueled buses),

-- HDDBT (diesel-fueled transit and urban buses), and

-- HDDBS (diesel-fueled school buses).

Therefore, we must combine the two transit and urban diesel-fueled classes as well as combine all three gasoline-fueled classes.

EPA noted in the MOBILE6 report on fleet distributions [6] the preponderance of gasoline-fueled buses is school buses. In that same report, when EPA determined the conversion factors to be used for HDDBT class, EPA weighted together the diesel-fueled transit buses equally with the diesel-fueled intercity buses.

Following this logic, EPA proposes combining the fuel economies for those six bus classes into the three MOBILE6 bus classes (from Appendix A) by using:

-- the fuel economies of gasoline-fueled school buses for the HDGB,

-- the fuel economies of diesel-fueled school buses for the HDDBS, and

-- the harmonic average of the fuel economies of diesel-fueled transit buses with the diesel-fueled intercity buses for the HDDBT.

This leads to the following table:

Table 5

Estimated Bus Fuel Economies (mpg) (by MOBILE6 classes)

Model Year	HDDBT	HDDBS	HDGB
1987	3.94	6.29	6.18
1988	3.99	6.28	6.21
1989	4.04	6.27	6.24
1990	4.08	6.25	6.27
1991	4.13	6.24	6.30
1992	4.17	6.23	6.33
1993	4.22	6.22	6.37
1994	4.26	6.20	6.40
1995	4.31	6.19	6.42
1996	4.36	6.18	6.45

2.3 Motorcycles

The third source of fuel economy estimates is an annual report prepared by the Bureau of Transportation Statistics of the U.S. Department of Transportation (DOT). In the current edition of that report **[4]**, the DOT compiled and published a variety of transportation statistics.

In this DOT analysis (specifically Table 4-22, entitled "Energy Intensity of Passenger Cars, Other 2-Axle 4-Tire Vehicles, and Motorcycles"), DOT estimates the total VMT in each of 13 calendar years (i.e., 1970, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, and 98) as well as the corresponding amounts of gasoline consumed. These motorcycle VMT and fuel consumption values are duplicated in the first three columns of Table 6. Dividing the VMT (column 2) by the amount of fuel consumed (column 3) produces an estimate of fleet fuel economy (i.e., the fourth column of Table 6). These estimated fuel economies of the in-use motorcycle fleet vary over the very narrow range of 49.56 to 50.26 miles per gallon (with a mean of 50.006). Based on this tiny variation in annual fleet fuel economies with no obvious trend (neither increasing nor decreasing with model year) in the in-use fleet fuel economies, EPA proposes to fix the fuel economies of this class at a constant 50.0 mpg for each model year. However, it has been suggested that DOT simply assumed a fuel economy of 50 mpg and then used that assumption along with its VMT estimates to predict the total gasoline consumed. If that were the case, then our attempt to use the DOT numbers to calculate fuel economy would be circular reasoning, and we would simply be accepting DOT's assumption that the fuel economy of on-road motorcycles averaged 50.0 mpg for each model year.

Table 6

DOT Estimates of Fuel Consumption of the In-Use Motorcycle Fleet

Calendar Year	VMT (millions of miles)	Gasoline Consumed (millions of gallons)	Calculated Fleet Fuel Economy (mpg)
1970	3,000	60	50.00
1975	5,600	113	49.56
1980	10,200	204	50.00
1985	9,100	182	50.00
1990	9,600	191	50.26
1991	9,200	184	50.00
1992	9,600	191	50.26
1993	9,900	198	50.00
1994	10,200	205	49.76
1995	9,800	196	50.00
1996	9,900	198	50.00
1997	10,100	202	50.00
1998	10,300	205	50.24

However, another source of fuel economy estimates **[8]** also assumes that motorcycle fuel economy is constant 50 mpg. This tends to validate our calculated values.

In a third source of fuel economy estimates of motorcycles, the DOT estimated **[9]** that the average fuel economy of on-road (only) motorcycles was about 43 mpg, the average fuel economy of off-road (recreational) motorcycles was about 59 mpg, and the average fuel economy of dual-purpose (i.e., both on-road and off-road) motorcycles averaged between 85 and 119 mpg. These values also tend to validate our value of 50 mpg for the average of all on-road motorcycles in MOBILE6.3

3.0 EXPANDING MODEL YEAR RANGES

In Sections 2.1 through 2.3, we developed estimated fuel economies for each of the 28 vehicle classes for a range of model years. MOBILE6.3 requires that those estimates be expanded to cover every model year from 1951 through 2050.

To expand those fuel economy estimates to the full range of model years, EPA proposes:

(1) to use the fuel economy estimated (in Section 2) for the earliest model year for all preceding model years (for each vehicle class) and

(2) to use the fuel economy estimated (in Section 2) for the latest (newest) model year for all subsequent model years (for each vehicle class).

4.0 COMPARING RESULTS WITH FUEL CONSUMPTION ESTIMATES

There are a number of estimates of highway fuel consumption that are based on measuring production of gasoline and diesel fuels. A comparison of these "top down" estimates with these proposed MOBILE6.3 "bottom up" estimates would serve to validate the fuel economy estimates in this report.

The preceding estimates of fuel economy are all given in units of miles per gallon. Thus, if estimates of total vehicle miles traveled (VMT) are known, then total fuel consumption can be estimated by dividing VMT by the corresponding fuel economy estimates.

4.1 Comparison with DOT Fuel Consumption Estimates

In a report recently published by DOT **[4, Tables 4-11 through 4-15]**, estimates of VMT (in millions of miles) and fuel consumption (in millions of gallons) are given by vehicle type for the 1998 calendar year. These values are reproduced below in Table 8:

Table 8

DOT Estimates of VMT and Fuel Consumption By Vehicle Type for 1998

Vehicle Types	VMT (millions of miles)	Fuel (millions of gallons)
Passenger cars	1,545,830	72,209
Motorcycles	10,260	205
Other Vehicle s with 2-Axles and 4-Tires	866,228	50,579
Single-Unit Trucks with 2-Axles and 6 or More Tires	67,894	9,741
Combination Trucks	128,159	21,100
Bus	6,996	1,049
Totals:	2,625,367	154,883

In this report, we have developed unique estimates for 20 truck classes (four light-duty* and 16 heavy-duty); however, in Table 8, there are only three truck types. And those three types are not based on gross vehicle weight ratings (GVWR) as are the MOBILE truck types. There is not a clear match between those two groups. In this comparison, we will simply merge these three truck types into a single "**ALL Truck**" group. Using the VMT weighting factors in MOBILE6.3, we can aggregate the MOBILE6.3 fuel economy estimates into those same groups.

Modifying Table 8 by combining the trucks into a single category and adding the corresponding MOBILE6.3 aggregated fuel economies produces Table 9. Dividing the VMTs** by the MOBILE6.3 fuel economies yields estimates of fuel consumption.

Table 9

Estimates of Annual VMT and Fuel Consumption By Vehicle Type for 1998

	DOT Estimates		---------- MOBILE6.3 Estimates ----------			
Vehicle Types	**VMT (millions of miles)**	**Fuel Used (millions of gallons)**	**VMT Fractions**	**VMT** (millions of miles)**	**Fuel Economies (mpg)**	**Fuel Used (millions of gallons)**
Passenger Cars	1,545,830	72,209	52.54%	1,379,298	23.41	58,922
Motorcycles	10,260	205	0.65%	17,130	50.00	343
ALL Trucks	1,062,281	81,420	46.53%	1,221,588	13.16	92,809
Bus	6,996	1,049	0.28%	7,351	5.32	1,381
Totals:	2,625,367	154,883		2,625,367		153,455

Thus, using the fuel economies in this report, the estimate of fuel (gasoline plus diesel) used in on-road (highway) vehicles in 1998 was 153.455 billion gallons which is within one percent of the DOT estimate of 154.883 billion gallons. Although those estimates of total fuel consumption are close, the estimates of fuel consumption by vehicle type do vary more due primarily to differences in estimates of VMT. The data in Table 9 are displayed graphically in Figure 1 (on the following page).

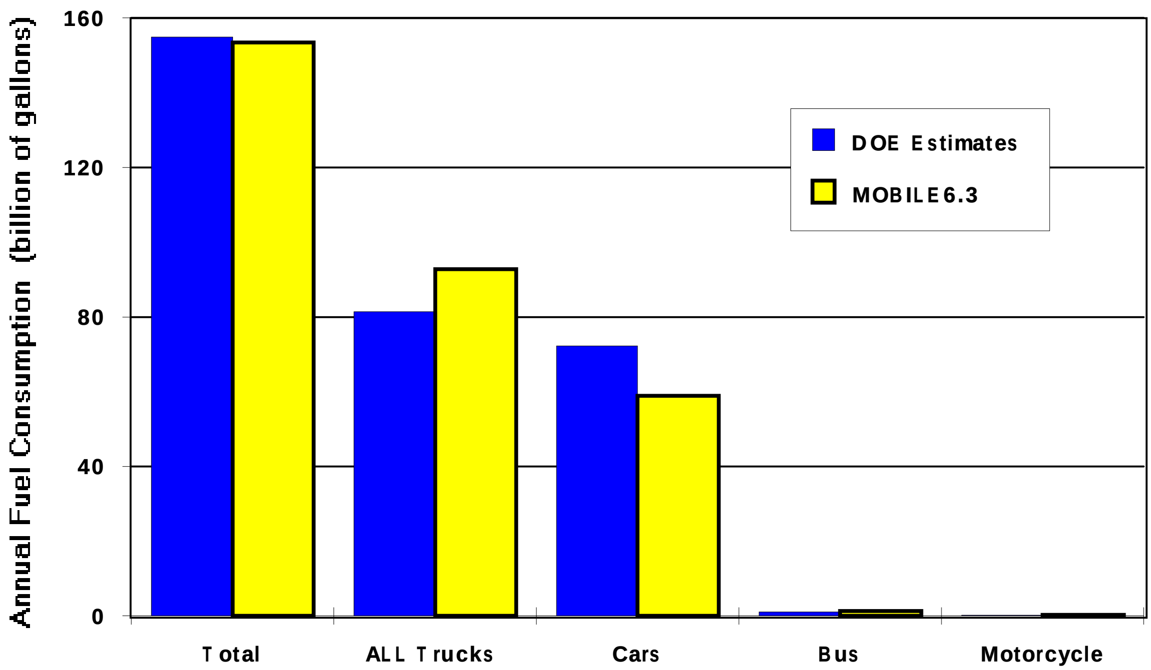
---

* In Appendix A, there are actually six light-duty truck classes; however, this report develops unique fuel economies for only four of them. (We combined the LDGT1 and LDGT2 to form the LDGT12. Similarly, we combined the LDGT3 and LDGT4 to form the LDGT34.

** MOBILE does not produce VMT estimates. The VMT fractions generated by MOBILE were multiplied by the total VMT (2,625,367 million miles) from DOT to obtain the MOBILE6.3 VMT values in Table 9.

Figure 1

Comparison of Estimates of Annual Fuel Consumption By Vehicle Type for 1998



4.2 Comparison with OAR and DOE CO2 Estimates

As explained in the introduction of this report, MOBILE6.3 uses the fuel economy estimates (along with the estimates of HC and CO emission factors) to calculate CO_2 emission factors. Using these CO_2 emission factors and the estimated VMTs from Table 9, we calculated the CO_2 emissions of the on-road (highway) fleet. Those estimates of fleet CO_2 emissions are given in Table 10. For comparison, Table 10 includes "top down" estimates of CO_2 emissions from a recent analysis of greenhouse gas (GHG) emissions by EPA's Office of Atmospheric Programs (which is within EPA's Office of Air (OAR)) **[10]**.

Table 10

Estimates of Annual CO_2 Emission
By Vehicle Type for 1998
(millions of metric tons)

	From GHG Report		MOBILE6.3 Estimates	
Vehicle Types	**CO_2 from Gasoline-Fueled Veh.**	**CO_2 from Diesel-Fueled Veh.**	**CO_2 from Gasoline-Fueled Veh.**	**CO_2 from Diesel-Fueled Veh.**
Passenger Cars	670.16	7.69	491.59	1.71
Motorcycles	1.83	---	2.50	---
ALL Trucks	373.74	229.74	520.45	299.51
Bus	2.20	9.16	2.10	10.92
Totals:	1,047.93	246.59	1,016.64	312.14

Thus, using the fuel economies in this report (and assuming a total fleet VMT of 2,625,367 million miles), the MOBILE6.3 estimate of CO_2 emissions produced by gasoline-fueled on-road (highway) vehicles in 1998 (1,016.64 million metric tons) was only 3.0 percent less than this "top down" model predicted. Similarly, the MOBILE6.3 estimate of CO_2 emissions produced by diesel-fueled on-road (highway) vehicles in 1998 (312.14 million metric tons) was 26.6 percent higher than the "top down" model predicted. And, the MOBILE6.3 estimate of total CO_2 emissions (1,328.78) was only about 2.6 percent higher than the "top down" model prediction of 1,294.52 million metric tons.

A second source for "top down" estimates of CO_2 emissions is from the Energy Information Administration (EIA)* of the US Department of Energy. EIA's estimates of CO_2 emissions (for calendar year 1998) from gasoline-fueled vehicles is 1,124 million metric tons and from diesel-fueled vehicles is 310 million metric tons. Combining these estimates with those from Table 10 produces Table 11 (on the following page).

* The fuel consumption estimates from EIA are available on their website (http://www.eia.doe.gov/).

Table 11

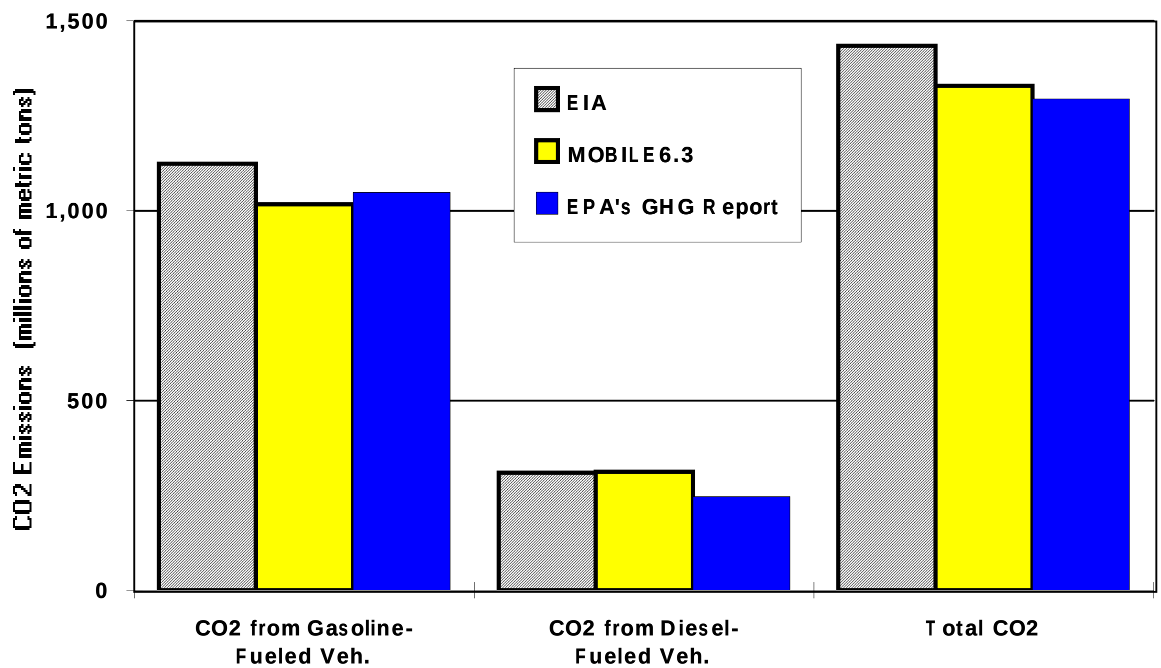
Estimates of Annual CO_2 Emission By Vehicle Type for 1998 (millions of metric tons)

Source of Estimates	CO_2 from Gasoline-Fueled Veh.	CO_2 from Diesel-Fueled Veh.	TOTAL
EIA	1,124	310	1,434
MOBILE6.3	1,017	312	1,329
EPA's GHG Report	1,048	247	1,295

The data in Table 11 are displayed graphically in Figure 2.

Figure 2

Comparison of Estimates of Annual CO_2 Emission by Fuel Type for 1998 (millions of metric tons)



From the data in Table 11 (or from Figure 2), we observe:

- The MOBILE6.3 prediction of total CO_2 emissions (from diesel plus gasoline) is between the estimates for the two "top down" models of CO_2 emissions.

- The MOBILE6.3 prediction of CO_2 emissions from gasoline-fueled vehicles is less than the estimates for the two "top down" models of CO_2 emissions. However, it is within three percent of the estimate of the estimate from the GHG report, and still within 10 percent of the EIA estimate.
- The MOBILE6.3 prediction of CO_2 emissions from diesel-fueled vehicles is more than the estimates for the two "top down" models of CO_2 emissions. However, it is within a fraction of a percent of the estimate of the estimate from the EIA.

Thus, this "bottom up" approach produces estimates (of fuel consumption and CO_2 emissions) within a few percent of those produced by three "top down" approaches (based on total national consumption of fuel).

These MOBILE6.3 "bottom up" predictions are very sensitive to estimates of the total miles driven which in turn are calculated by using estimates of population size (by model year and by vehicle type) and estimates of the average miles driven annually (again, by model year and by vehicle type). Shifting those estimates of either fleet size or VMT could easily account for the differences among the estimates.

Also, the "top down" approach (based on total national consumption of fuel) has its own set of uncertainties. For example, even if the exact amount of gasoline consumed nationally were known, determining the portion of that amount to allocate to on-road (versus non-road) uses is based on several assumptions (each containing some degree of uncertainty).

Nevertheless, the two approaches appear to confirm that the estimates of fuel economy are accurate given the quality of data available.

5.0 REFERENCES

1. K. Hellman and R.M. Heavenrich, "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 Through 2001," EPA Report Number EPA420-R-01-008, September 2001. (Available at: http://www.epa.gov/otaq/fetrends.htm)

2. R.M. Heavenrich and J.D. Murrell, "Light-Duty Automotive Technology and Fuel Economy Trends Through 1989," EPA Report Number EPA/AA/CTAB/89-04, May 1989.

3. L. Browning, "Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6: Analysis of Fuel Economy, Non-Engine Fuel Economy Improvements, and Fuel Densities," (prepared by ARCADIS Geraghty & Miller, Inc. for the USEPA) EPA Report Number EPA420-P-98-014 (MOBILE6 Report Number M6.HDE.002), May 1998. (Available at: http://www.epa.gov/otaq/models/mobile6/m6hde002.pdf)

4. "National Transportation Statistics 2000," Published by the Bureau of Transportation Statistics of the U.S. Department of Transportation, Report Number BTS01-01, April 2001. (Available at: http://www.bts.gov/btsprod/nts/)

5. M. Mintz, A.D. Vyas, L.A. Conley, "Differences Between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?" Paper No. 931104, Transportation Research Board, Washington, DC., 1993.

6. T. Jackson, "Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage Accumulation Rates, and Projected Vehicle Counts for Use in MOBILE6," EPA Report Number EPA420-R-01-047 (MOBILE6 Report Number M6.FLT.007), September 2001. (Available at: http://www.epa.gov/otaq/models/mobile6/r01047.pdf)

7. EPA's "Mobile Source Observational Data Base" (MSOD). (Information at: http://www.epa.gov/otaq/models.htm#msod)

8. "California Motor Vehicle Stock, Travel And Fuel Forecast," California Department of Transportation, Office of Traffic Improvement, November 1993. (Available at: http://ntl.bts.gov/DOCS/cal.html)

9. S.C. Davis, L.F. Truett, and P.S. Hu, "Fuel Use for Off-Road Recreation: A Reassessment of the Fuel Use Model," Office of Highway Information Management, U.S. Department of Transportation, DOT Report Number ORNL/TM-1999/100, July 1999, pages 20-22.

10. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998," Office of Atmospheric Programs, U.S. EPA, EPA Report Number EPA 236-R-00-001, April 2000, Table 2-8, page 2-10.

Appendix A

Vehicle Classes in MOBILE6

No.	Abbrev.	Description
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8500 lbs. GVWR, 0-3750 lbs. LVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8500 lbs. GVWR, 3,751-5750 lbs. LVW)
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (Over 60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8501-10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (Over 60,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

Appendix B

Passenger Car Fuel Economy by Model Year

(Reproduced from Table 1 of Reference 1)

Model Year	Lab Composite*	<==== Adjusted ===> FTP	HFET	Composite*
1975	15.8	12.3	15.2	13.5
1976	17.5	13.7	16.6	14.9
1977	18.3	14.4	17.4	15.6
1978	19.9	15.5	19.1	16.9
1979	20.3	15.9	19.2	17.2
1980	23.5	18.3	22.6	20.0
1981	25.1	19.6	24.2	21.4
1982	26.0	20.1	25.5	22.2
1983	25.9	19.9	25.5	22.1
1984	26.3	20.2	26.0	22.4
1985	27.0	20.7	26.8	23.0
1986	27.9	21.3	27.7	23.8
1987	28.1	21.5	28.0	24.0
1988	28.6	21.8	28.5	24.4
1989	28.1	21.4	28.3	24.0
1990	27.8	21.1	28.1	23.7
1991	28.0	21.2	28.3	23.9
1992	27.6	20.8	28.3	23.6
1993	28.2	21.3	28.8	24.1
1994	28.1	21.1	28.8	24.0
1995	28.3	21.2	29.3	24.2
1996	28.3	21.2	29.3	24.2
1997	28.4	21.3	29.4	24.3
1998	28.5	21.3	29.6	24.4
1999	28.2	21.1	29.2	24.1
2000	28.3	21.2	29.3	24.2
2001	28.3	21.2	29.3	24.2

* Composite fuel economies are a weighted harmonic average 55 percent FTP and 45 percent HFET. They are referred to as "55/45" in Reference 1.

Appendix C

Light-Truck Fuel Economy by Model Year

(Reproduced from Table 1 of Reference 1)

Model Year	Lab Composite	<==== Adjusted ===> FTP	HFET	Composite
1975	13.7	10.9	12.7	11.6
1976	14.4	11.5	13.2	12.2
1977	15.6	12.6	14.1	13.3
1978	15.2	12.4	13.7	12.9
1979	14.7	12.1	13.1	12.5
1980	18.6	14.8	17.1	15.8
1981	20.1	16.0	18.6	17.1
1982	20.5	16.3	19.0	17.4
1983	20.9	16.5	19.6	17.8
1984	20.5	16.1	19.3	17.4
1985	20.6	16.2	19.4	17.5
1986	21.4	16.9	20.2	18.3
1987	21.6	16.9	20.7	18.4
1988	21.2	16.5	20.4	18.1
1989	20.9	16.3	20.1	17.8
1990	20.7	16.1	20.2	17.7
1991	21.3	16.4	20.7	18.1
1992	20.8	16.1	20.4	17.8
1993	21.0	16.1	20.7	17.9
1994	20.8	16.0	20.4	17.7
1995	20.5	15.8	20.2	17.5
1996	20.8	16.0	20.7	17.8
1997	20.6	15.8	20.4	17.6
1998	20.9	16.0	20.8	17.8
1999	20.5	15.7	20.3	17.5
2000	20.5	15.7	20.3	17.5
2001	20.3	15.6	20.0	17.3

Appendix D

Penetration of Diesels in the Light-Duty Fleet by Model Year

(Reproduced from Table 18 of Reference Number 6)

Model Year	Passenger Cars	Light-Duty Trucks 1 and 2	Light-Duty Trucks 3 and 4
1974 and Earlier	0.67%	11.70%	0.01%
1975	1.55%	10.38%	0.00%
1976	1.37%	1.87%	0.00%
1977	0.93%	0.00%	0.00%
1978	1.14%	2.59%	0.01%
1979	2.69%	3.16%	0.11%
1980	3.90%	4.39%	0.06%
1981	7.06%	6.16%	0.13%
1982	5.10%	6.56%	2.56%
1983	2.41%	2.23%	2.09%
1984	1.62%	1.20%	1.69%
1985	0.97%	0.48%	1.35%
1986	0.32%	0.33%	1.24%
1987	0.27%	0.07%	0.82%
1988	0.01%	0.00%	0.72%
1989	0.04%	0.00%	0.83%
1990	0.04%	0.00%	0.96%
1991	0.13%	0.00%	1.29%
1992	0.06%	0.00%	1.15%
1993	0.03%	0.00%	1.45%
1994	0.01%	0.00%	1.11%
1995	0.06%	0.00%	1.15%
1996 and Later	0.09%	0.00%	1.26%

Appendix E

Light-Duty Fuel Economy by Model Year

(Compiled from Tables 6 and 7 of Reference Number 2)

(Fuel Economy Values Are NOT Adjusted)

Model	<=== Passenger Cars ===>			<=== Light Trucks ===>		
Year	Gasoline	Diesel	Combined	Gasoline	Diesel	Combined
1978	19.8	29.4	19.9	15.2	21.2	15.2
1979	20.1	27.1	20.3	14.7	21.1	14.7
1980	23.3	30.0	23.5	18.4	24.3	18.6
1981	24.9	29.9	25.1	19.7	32.0	20.1
1982	25.9	30.6	26.0	20.0	27.0	20.5
1983	25.8	30.8	25.9	20.7	27.0	20.9
1984	26.2	36.3	26.3	20.4	27.4	20.5
1985	26.9	34.2	27.0	20.5	26.1	20.6
1986	27.9	40.5	27.9	21.4	26.7	21.4
1987	28.0	30.5	28.1	21.6	25.6	21.6
1988	28.6	37.4	28.6	21.1	22.2	21.2
1989	28.1	44.3	28.1	20.9	22.6	20.9

Appendix F

Merging Appendices B, C, and E

(ALL Fuel Economies Are Adjusted "Lab" 55/45)

Model	<=== Passenger Cars ===>			<=== Light Trucks ===>		
Year	Gasoline	Diesel	Combined	Gasoline	Diesel	Combined
1975	---	---	13.5	---	---	11.6
1976	---	---	14.9	---	---	12.2
1977	---	---	15.6	---	---	13.3
1978	16.8	25.0	16.9	12.9	18.0	12.9
1979	17.1	23.0	17.2	12.5	17.9	12.5
1980	19.8	25.5	20.0	15.7	20.7	15.8
1981	21.2	25.4	21.4	16.7	27.2	17.1
1982	22.0	26.0	22.2	17.0	23.0	17.4
1983	21.9	26.2	22.1	17.6	23.0	17.8
1984	22.2	30.9	22.4	17.3	23.3	17.4
1985	22.9	29.1	23.0	17.4	22.2	17.5
1986	23.7	34.4	23.8	18.2	22.7	18.3
1987	23.8	25.9	24.0	18.4	21.8	18.4
1988	24.3	31.8	24.4	17.9	18.9	18.1
1989	23.9	37.7	24.0	17.8	19.2	17.8
1990	---	---	23.7	---	---	17.7
1991	---	---	23.9	---	---	18.1
1992	---	---	23.6	---	---	17.8
1993	---	---	24.1	---	---	17.9
1994	---	---	24.0	---	---	17.7
1995	---	---	24.2	---	---	17.5
1996	---	---	24.2	---	---	17.8
1997	---	---	24.3	---	---	17.6
1998	---	---	24.4	---	---	17.8
1999	---	---	24.1	---	---	17.5
2000	---	---	24.2	---	---	17.5
2001	---	---	24.2	---	---	17.3

Appendix G

Estimating Missing Values for Appendix F

Model Year	<=== Passenger Cars ===> Gasoline	Diesel	Combined	<=== Light Trucks ===> Gasoline	Diesel	Combined
1975	*13.4*	*24.0*	13.5	*11.2*	*18.0*	11.6
1976	*14.8*	*24.0*	14.9	*12.1*	*18.0*	12.2
1977	*15.5*	*24.0*	15.6	*13.2*	*18.0*	13.3
1978	16.8	25.0	16.9	12.9	18.0	12.9
1979	17.1	23.0	17.2	12.5	17.9	12.5
1980	19.8	25.5	20.0	15.7	20.7	15.8
1981	21.2	25.4	21.4	16.7	27.2	17.1
1982	22.0	26.0	22.2	17.0	23.0	17.4
1983	21.9	26.2	22.1	17.6	23.0	17.8
1984	22.2	30.9	22.4	17.3	23.3	17.4
1985	22.9	29.1	23.0	17.4	22.2	17.5
1986	23.7	34.4	23.8	18.2	22.7	18.3
1987	23.8	25.9	24.0	18.4	21.8	18.4
1988	24.3	31.8	24.4	17.9	18.9	18.1
1989	23.9	37.7	24.0	17.8	19.2	17.8
1990	*23.6*	*32.4*	23.7	*17.6*	*20.6*	17.7
1991	*23.8*	*32.4*	23.9	*18.0*	*20.6*	18.1
1992	*23.5*	*32.4*	23.6	*17.7*	*20.6*	17.8
1993	*24.0*	*32.4*	24.1	*17.8*	*20.6*	17.9
1994	*23.9*	*32.4*	24.0	*17.6*	*20.6*	17.7
1995	*24.1*	*32.4*	24.2	*17.4*	*20.6*	17.5
1996	*24.1*	*32.4*	24.2	*17.7*	*20.6*	17.8
1997	*24.2*	*32.4*	24.3	*17.5*	*20.6*	17.6
1998	*24.3*	*32.4*	24.4	*17.7*	*20.6*	17.8
1999	*24.0*	*32.4*	24.1	*17.4*	*20.6*	17.5
2000	*24.1*	*32.4*	24.2	*17.4*	*20.6*	17.5
2001	*24.1*	*32.4*	24.2	*17.2*	*20.6*	17.3

Appendix H

Expanding Fuel Economy Estimates
From Appendix G to ALL Light-Duty Classes

Model Year	<=== Gasoline-Fueled ===> LDGV	LDGT12	LDGT34	<=== Diesel-Fueled ===> LDDV	LDDT12	LDDT34
1975	13.4	12.0	9.3	24.0	19.4	14.9
1976	14.8	13.0	10.0	24.0	19.4	14.9
1977	15.5	14.2	10.9	24.0	19.4	14.9
1978	16.8	13.9	10.7	25.0	19.4	14.9
1979	17.1	13.4	10.3	23.0	19.3	14.8
1980	19.8	16.8	12.9	25.5	22.2	17.1
1981	21.2	18.0	13.8	25.4	29.2	22.5
1982	22.0	18.3	14.1	26.0	24.7	19.0
1983	21.9	18.9	14.5	26.2	24.7	19.0
1984	22.2	18.6	14.3	30.9	25.0	19.3
1985	22.9	18.7	14.4	29.1	23.8	18.3
1986	23.7	19.6	15.0	34.4	24.4	18.8
1987	23.8	19.7	15.2	25.9	23.4	18.0
1988	24.3	19.3	14.8	31.8	20.3	15.6
1989	23.9	19.1	14.7	37.7	20.7	15.9
1990	23.6	18.9	14.6	34.2	22.1	17.0
1991	23.8	19.4	14.9	34.2	22.1	17.0
1992	23.5	19.0	14.6	34.2	22.1	17.0
1993	24.0	19.1	14.7	34.2	22.1	17.0
1994	23.9	18.9	14.6	34.2	22.1	17.0
1995	24.1	18.7	14.4	34.2	22.1	17.0
1996	24.1	19.0	14.6	34.2	22.1	17.0
1997	24.2	18.8	14.5	34.2	22.1	17.0
1998	24.3	19.0	14.6	34.2	22.1	17.0
1999	24.0	18.7	14.4	34.2	22.1	17.0
2000	24.1	18.7	14.4	34.2	22.1	17.0
2001	24.1	18.5	14.2	34.2	22.1	17.0

Appendix I

TIUS Fuel Economy Survey Data on Which Tables 2 and 3 Are Based (from Reference 3, Tables A-1 through A-15)

Summarized Gasoline Heavy-Duty Vehicle Fuel Economies (mpg)

Model Year	Weight Classes: 2b	3	4	5	6	7	8A	8B
83	9.2	7.1	6.5	6.7	6.3	7.6	4.5	--
84	8.6	8.4	6.3	8.2	7.2	6.0	8.5	--
85	9.0	8.3	8.1	7.0	7.3	6.7	5.8	--
86	8.7	8.2	7.7	7.3	7.5	6.6	6.4	--
87	9.4	9.1	7.9	8.4	6.8	6.1	8.5	--
88	9.7	8.8	8.1	7.2	7.9	7.7	5.6	--
89	9.4	10.2	9.0	6.3	6.9	5.7	5.1	--
90	9.7	9.6	9.9	8.5	7.7	7.7	7.2	--
91	8.7	8.9	9.5	7.6	8.8	7.7	7.8	--
92	10.4	10.7	8.9	7.3	7.6	13.8	6.3	--

Summarized Diesel Heavy-Duty Vehicle Fuel Economies (mpg)

Model Year	Weight Classes: 2b	3	4	5	6	7	8A	8B
83	10.8	9.8	8.1	7.6	8.0	5.9	5.5	5.2
84	13.2	9.6	6.4	8.1	8.0	7.0	5.7	5.3
85	11.3	11.0	8.3	9.9	7.6	7.7	5.9	5.3
86	12.2	11.9	9.0	8.4	8.1	7.3	6.0	5.5
87	11.7	10.6	9.5	9.2	8.3	7.6	6.1	5.5
88	11.8	11.8	9.7	9.9	8.9	8.0	6.1	5.5
89	12.4	10.6	10.4	10.7	8.8	7.2	5.9	5.7
90	11.6	11.6	10.1	9.2	8.1	7.4	6.1	5.8
91	12.0	11.2	12.9	9.4	8.2	7.3	6.4	5.9
92	12.4	11.1	9.9	9.7	8.3	7.5	6.2	6.0

Appendix J

Response to Peer Review Comments from Christian Lindhjem, ENVIRON Corp.

An earlier version of this report was formally peer reviewed by two peer reviewers (Christian Lindhjem and Marc Ross). In this appendix, comments from Christian Lindhjem are reproduced in plain text, and EPA's responses to those comments are interspersed in indented italics. Comments from the other peer reviewer appear in the following appendix (Appendix K).

****

ENVIRON Review of

EPA Draft Report:
"Updating Fuel Economy Estimates in MOBILE6.3"

Prepared for

EPA
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, MI 48105-2425

Prepared by

Christian Lindhjem
ENVIRON International Corporation
101 Rowland Way, Suite 220
Novato, CA 94945

10 June 2002

Introduction

Overall, this report reasonably details the conventional understanding of the in-use fuel economy for current and past model year vehicles. While these estimates may indeed be accurate within the scope and intent of this model, there are clear limitations with these estimates. Therefore, the intended use of MOBILE6.3 needs to be clearly stated and consistent with the simplifying assumptions used in these estimates. The estimates provided in this work only sought to distinguish vehicle fuel consumption by model year and general vehicle types such as diesel and gasoline light-duty cars, 2 kinds of pick-up trucks, and heavy-duty vehicles of various gross vehicle weight ratings (GVWR). All other differences that could affect fuel economy were ignored limiting the model's use to just these variables.

RESPONSE: *The Users Guide for MOBILE6.3 (which is being drafted) will stress these limitations.*

For light-duty vehicle, the current fuel economy information gathered through the certification procedure is the ultimate source of data used to determine fuel economy distinguishing only by vehicle type and model year. One in-use adjustment was given to all vehicles ignoring fuel economy improvements that might be experienced in use by technology type, model year, or as vehicles age. This limits the analysis to differences experienced only during the certification test procedure when the vehicles are first certified.

For heavy-duty vehicles, the current fuel economy information is based on, what is now called, the VIUS surveys (http://www.census.gov/svsd/www/tiusview.html). Because the fuel economy was determined from in-use surveys, no in-use adjustment was needed. As with the light-duty estimates, the heavy-duty estimates only distinguish by vehicle type and model year.

RESPONSE: *A statement to that effect has been added to Section 2.2.*

Specific Issues

On page 3, the light-duty adjustment was not well described and needs to be explained in greater detail. Searching the referenced source, the most recent Fuel Economy Trends report, did not provide a clear explanation of these adjustments. An early report (SAE-820791) described a statistical regression of in-use survey data and distinguished the adjustment through the variables of number of cylinders, front-wheeled drive, manual transmission, fuel injection, and diesel. Could these variables have been used to determine the adjustment by technology type and combined with sales data could have provided unique adjustments by model year? The in-use adjustment therefore needs to be discussed in greater detail especially in regards to the effect that model year or technology type might have in the estimates used in the model. MOBILE6 described an improvement of the emission deterioration with newer model year vehicles, so it would be expected that such reduced deterioration might lead to an improvement in in-use fuel consumption performance as well.

RESPONSE: *It is true that a number of different approaches for creating adjustment factors are possible. At the time of that SAE paper (around 1982), EPA considered the same approaches identified by this reviewer to adjust its official fuel economy estimates. EPA eventually settled on the approach used in this report. Since EPA began adjusting the dynamometer test results to better approximate on-road fuel economies (beginning with the 1985 model year), the* ***ONLY*** *adjustment factors used by EPA have been the reduction of the FTP fuel economy values by 10 percent and the reduction of the HFET values by 22 percent (effectively reducing the composite values by about 15 percent). EPA will continue to use these historic adjustment factors in this interim model. At the suggestion of the reviewer,* *we have expanded the discussion (on page 3) of these adjustment factors.*

Also on page 3, it is stated that the relative mileage on the city and highway driving cycles, the 55/45 composite value, is an appropriate estimate of real world (in-use) conditions. EPA should either justify this claim through national VMT estimates, determining whether such an estimate is accurately historically, or a discussion needs to be added to include this estimate to the list of limitations of MOBILE6.3.

RESPONSE: *As with the previous point, the 55/45 (FTP/HFET) split is EPA's official (and historic) approach to simulating actual vehicle usage. It is used in EPA's Gas Guzzler and CAFE programs. Also, this composite value (after "adjusting") is used in EPA's fuel economy labeling program for new light-duty vehicles. Therefore, the use of this weighted composite value to represent real-world driving has already been discussed.*

On page 6, it is stated that in-use vehicle weight data for light-duty trucks was taken from the Mobile Source Observational Database (MSOD) to allow for distinguishing between LDT12 from LDT34. Any data set should be accompanied by a discussion of the potential selection bias, though in this case the vehicle weights were only used to determine a ratio of curb weights so selection bias may be masked. However for instance, one could envision a circumstance where LDT34 may have higher in-use curb weights compared with LDT12 than in the data set because of selection bias by choosing fewer commercially licensed work trucks or removal of tools or other loads prior to testing for the MSOD.

RESPONSE: *The data in the MSOD was gathered for dozens of individual work assignments. Therefore, while the vehicle selection criteria of an individual work assignment might have been skewed (i.e., biased), we believe that combined vehicle recruitment was most likely representative. However, the reviewer is correct in that none of the test results included the effects of cargo (including work tools). Including tools, passengers, and other cargo would increase the weight of the vehicle above the dynamometer test weight (possibly as high as the GVWR). This increase in vehicle weight would result in a decrease in fuel economy and may be one of the reasons that those EPA fuel economy "adjustment factors" are necessary.*

On page 8 with the table on page 9, no discussion of the effect of the heavy-duty defeat device is provided even though this issue figured prominently in MOBILE6. While it may be difficult to assess the fuel economy effect of the defeat device, the lack of discussion begs the question, so a discussion needs to be included.

RESPONSE: *A discussion has been added to the top of page 10 on this question. Additionally, the raw fuel economy values (in Appendix I) indicate that the increases in* *the fuel economy of the diesel-fueled heavy-duty trucks parallel the increases of the corresponding gasoline-fueled heavy-duty trucks. This suggests that the fuel economy improvements of those diesel-fueled heavy-duty trucks may result from improvements to tires and aerodynamics rather than to alleged NO_X defeat devices.*

On page 14, when estimating the total fuel consumption, the discussion of the vehicle miles traveled (VMT) needs to be accompanied by a discussion of how the vehicle mix (fraction of VMT by vehicle type) and the diesel/gasoline fractions were developed.

RESPONSE: *The approach was revised to simply use the MOBILE6 VMT fractions along with the total fleet VMT. The footnote to Table 9 was added to explain this.*

On page 16, the fuel consumption estimates available from EIA (http://www.eia.doe.gov/), could also be used to compare with the estimates provided here. Based on the EIA estimates, a comparison with the estimates in Table 10 can be made and is shown in Table 1. There may be a number of reasons why the EIA estimates are higher than those predicted by MOBILE6.3 including the use of highway fuel in nonroad engines, spillage, or other losses or uses.

Table 1. Comparison of 1998 CO2 emissions (millions of metric tons).

GHG		MOBILE6.3 Estimates		EIA Estimates	
Gasoline	**Diesel**	**Gasoline**	**Diesel**	**Gasoline**	**Diesel**
1,048	247	991	274	1,124	310
1,295		1,265		1,434	

RESPONSE: *As the reviewer suggested, Table 11 was added to include the fuel consumption estimates of the Energy Information Administration (EIA).*

Discussion and Recommendation for Future Work

This report could provide a blueprint for future work suggesting issues that need to be investigated. Future work needs to address many factors, but the most important estimate in the current work that needs to be investigated more thoroughly is the in-use adjustment discussed in detail in SAE-820791 and shown below. Vehicle emission standards (such as improved cold start controls from emission standards, off-cycle testing procedures, evaporative controls), in-use programs (inspection and maintenance or on-board diagnostics), or other programs may affect the in-use adjustment to light-duty fuel economy.

RESPONSE: *It is anticipated that future models will rely heavily on actual in-use test results. Therefore, these adjustment factors may not be necessary in the future models.*

Factors Affecting Fuel Economy (from SAE-820791)

Production Slip
Administrative variance
Hardware variance

Vehicle Condition
Engine tune
Engine response to fuel properties
Sampling bias

Travel Environment
Ambient temperature
Barometric Pressure/Altitude
Wind and Aerodynamics
Road Gradient
Road Surface
Road Curvature

Travel Characteristic
Vehicle speed
Traffic volume effects
Trip length/Vehicle warm up
Acceleration intensity

Vehicle Condition
Wheel mechanical condition
Tire pressure
Vehicle weight load

The effect on fuel economy of each of these factors could be influenced by the technology type, model year, or maintenance condition of vehicles. The current estimates of the in-use adjustment in this draft EPA report ignore these factors.

RESPONSE: *These factors were intentionally ignored for this interim model. They will be considered in future models.*

In addition, there was no discussion of CNG/LPG or other alternatively fueled vehicles. MOBILE6 has included emission estimates for these vehicles; so it may be important to include such estimates in MOBILE6.3 raise questions *(sic)*. Applications that have begun to use CNG (or LNG) and LPG-fueled vehicles included many light-duty vehicles and transit buses, refuse trucks, and other heavy-duty vehicles, so a comparison of such technologies might be a useful purpose for MOBILE6.3.

RESPONSE: *The fuel economies of vehicles other than diesel-fueled or gasoline-fueled are outside the scope of MOBILE6.3. They will be considered when the analyses for the New Generation GHG model are performed.*

Also, fuel differences, such as summer/winter, reformulated or oxygenated gasoline and diesel, were not discussed. The energy content of these fuels may affect the overall estimates of fuel consumption in mile per gallon. A consideration of these effects need to included if the predicted fuel consumption is to be compared with fuel sales or production.

RESPONSE: *The effects of those parameters are outside the scope of MOBILE6.3. They will be considered when the analyses for the New Generation GHG model are performed.*

It is expected that the future editions of the MOBILE6.3 model would include the technology and analysis being developed for future regulated emissions modeling (such as described at http://www.epa.gov/otaq/ngm.htm). It would be helpful therefore to describe how new emissions/fuel consumption data will be used to improve the fuel consumption estimates provided here.

RESPONSE: *After MOBILE6.3 is completed, we do not plan to prepare additional "editions." Instead, our efforts will focus on the New Generation GHG model. However, the User's Guide for MOBILE6.3 will explain how to alter the default fuel economy estimates so that the users may model various future scenarios.*

When making comparisons with fuel consumption predictions, it is useful to determine the uncertainty of the estimates provided. It is particularly important for MOBILE6.3 where many of the estimates are based on proprietary information, such as the confidential business information of sales figures, which prevent independent assessment of the results provided in this report. An uncertainty analysis is important not only for assessing the predictions made by the model but in improving the estimates by targeting future work toward estimates with the greatest uncertainty.

RESPONSE: *Analyses of uncertainty have not been performed for any of the versions of MOBILE6. A limited discussion of the uncertainty (qualitative not quantitative) in the total fleet CO2 emissions and fuel consumption is included on page 19. The question of uncertainty will be considered when the analyses for the New Generation GHG model are performed.*

Appendix J-1

Appendix (to Peer Reviewer's Report)
Editorial/Typographical Errors

On page 7, there was a typo where the reference “Tables 3 and 4” should be “Tables 2 & 3”.

RESPONSE: *The text has been corrected.*

On the top of page 10, there is a description of the trends shown in Tables 2 and 3, but these trends were smoothed regressions of the TIUS results. Therefore, it is not surprising that these trends would be consistent.

RESPONSE: *The text has been revised, and Appendix I (which contains the TIUS "raw" fuel economies) has been added.*

Appendix K

Response to Peer Review Comments from Marc Ross, University of Michigan

This report was formally peer reviewed by two peer reviewers (Christian Lindhjem and Marc Ross). In this appendix, comments from Marc Ross are reproduced in plain text, and EPA's responses to those comments are interspersed in indented italics. Comments from the other peer reviewer appear in the preceding appendix (Appendix J).

****

Review of "Updating Fuel Economy Estimates in MOBILE6.3",
by Larry C. Landman, March 26, 2002

Suggestions

p 3 The Hellman-Murrell fuel economy adjustment is still in use, but one may question whether the factors are still valid after almost 20 years with their changes in vehicles, roads and speeds. We don't have anything that's better, so I suggest adding cites, but not changing the calculation. One cite is Mintz, Marianne, Anant Vyas, and L. A. Conley 1993, "Differences Between EPA-test and In-use Fuel Economy: Are the Correction Factors Correct?" Paper No. 931104, Transportation Research Board, Washington, DC.

RESPONSE: *A footnote to that effect has been added to the bottom of page 3. Also, it is anticipated that future models will rely heavily on actual in-use test results. Thus, these adjustment factors may not be necessary in future models.*

p 6 The fraction of LDT12 among LDT1234, and the ratio of fuel economies for them are a bit troubling. In the Fleet Characterization Data for MOBILE6 (Jackson) Table 10, it says MOBILE6 LDT3 has GVWR >6000 lbs and includes most 1/2 ton pickups (others being LDT4). But Buyers' Guides shows popular 1/2 ton pickups with GVW (curb weight plus maximum payload) under 5000 lbs for Ranger and S-10 in 1991; and 1/2 ton full size pickups are just under and over 6000 lbs. So I find the sales fraction for LDT12 may be > 2/3. Moreover Jackson Table 13, shows 74% for LDT12 among LDT1234 for 1996, which may have been the data year for that analysis.

RESPONSE: *The reviewer is correct; the actual ratio should be about three-fourths (not two-thirds). The text has been corrected. The values in Section 4.0 and in Appendix H have been recalculated.*

In the same vein, if I look at the fuel economies of pickups, I see a big difference between Ranger and S-10 on the one hand, and the 3/4 and 1 ton pickups on the other.

RESPONSE: *This is not unexpected since the fuel economies within each vehicle class can vary greatly.*

In addition, the footnote on page 6 is ambiguous as it talks about the ratio of LDT12 to LDT34 where presumably it's LDT12 to LDT1234.

RESPONSE: *That footnote has been corrected.*

I haven't done any analysis here, just looked at a few examples among pickups including a look at sales in 1990; and have not considered vans.

p14 The unstated assumption in the comparisons of fuel consumption based on DOT and MOBILE6 is that vehicle fuel economy doesn't change over the life of the vehicle. (Since the DOT data is based on vehicles of all ages and the EPA data on new vehicles.)

RESPONSE: *A statement to that effect has been added just prior to Section 2.1.1.*

One would expect some change in fuel economy with vehicle age, for example as tire pressure and tire rolling resistance change, engine friction changes, and possibly an external rack is added. A cite is Ang, B.W., T.F. Fwa, et al. "A Statistical Study on Automobile Fuel Consumption", Energy vol 16, no. 1, pp1067-1077, 1991.

On the other hand, I once looked at CO2 emissions by odometer reading in the FTP surveys by EPA and could not find an effect.

RESPONSE: *Our assumption that fuel economy does not change as vehicles age is controversial and probably overly simplistic. In future models, vehicle age (as well as other variables) will be considered.*

Other Comments

p2 The motivations for the work are well explained, i.e. the need to separate diesel from gasoline-fueled vehicles, the need for documentation, and the decision not to include local or regional differences in driving. The need to definitively separate diesel from gasoline-fueled vehicles for carbon analysis could be stated explicitly.

RESPONSE: *A statement to that effect has been added to the beginning of Section 2.1.1.*

pp 4,5 The decisions made on diesel penetrations and fuel economies are well justified by the small number of diesels at issue - that were produced or that are still on the road.

pp 7,8,9 It appears at first glance that the ratios of the coefficients, B/A, vary too much for one to be comfortable extrapolating them into the future, unless one had information on differences in model changes. (Compare, for example, HDV3 with HDV7.) However, the time dependence of the B terms is slight. Thus for HDV3 the fuel economy ratio for MY96 to MY92 is 1.046, while that for HDV7 is 1.007, a difference of only 4%.

RESPONSE: *The reviewer is correct that the fuel economy changes only very slightly with time (i.e., model year). These regression equations were used (in Reference Number* **3***) to extrapolate the fuel economies only for a relatively short time into the future (i.e., four years).*

pp 10,11 It is a good choice to focus the classification on school buses as done here.

p 12 The last comments before Table 6 are wonderful.

p 13 The decision about expanding the model year range into the past is good. One can only hope that the extension into the distant future will prove highly inaccurate, but that applications of MOBILE6.3 will, at most, involve model years only a few years beyond the present.

p 14 In the first sentence below Table 8 it says "four light-duty" truck classes, but Appendix A has 4 LDGT and 2 LDDT listed.

RESPONSE: *In this report, the LDGT1 and LDGT2 were combined into a single class (LDGT12) as were the LDGT3 and LDGT4 (forming LDGT34). A footnote was added explaining this.*

p 17 The most critical statement is made just below Fig. 2. The VMT estimates are crude.

RESPONSE: *The combined fleet estimates are very sensitive to VMT which is itself difficult to estimate.*

Appendices The tables are clear and easy to understand. The table number from which the data was taken is not shown for App E.

RESPONSE: *The data in Appendix E were compiled from values in Tables 6 and 7 of the 1989 "Trends" report. Those table numbers have now been added to Appendix E.*