United States Environmental Protection Agency
Air and Radiation
EPA420-P-98-015
May 1998

Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6: Analysis of BSFCs and Calculation of Heavy-Duty Engine Emission Conversion Factors

Printed on Recycled Paper

UPDATE HEAVY-DUTY ENGINE EMISSION CONVERSION FACTORS FOR MOBILE6

Analysis of BSFCs and Calculation of Heavy-Duty Engine Emission Conversion Factors

05 May 1998

PREPARED FOR

U.S. Environmental Protection Agency
Motor Vehicle Emissions Laboratory
2565 Plymouth Road
Ann Arbor, Michigan 48105

Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6

Analysis of BSFCs and Calculation of Heavy-Duty Engine Emission Conversion Factors

Prepared for:
U.S. Environmental Protection Agency
Motor Vehicle Emissions Laboratory
2565 Plymouth Road
Ann Arbor, Michigan 48105

Prepared by:
Louis Browning
ARCADIS Geraghty & Miller, Inc.
555 Clyde Avenue
P.O. Box 7044
Mountain View
California 94039
Tel 650 961 5700
Fax 650 254 2496

Our Ref.:
SJ007258

Date:
05 May 1998

This report and the information and data described herein have been funded by the USEPA under Contract 68-C6-0068, Work Assignments #0-03 and 1-02. It is being released for information purposes only. It may not reflect the views and positions of the USEPA on the topics and issues discussed, and no official endorsement by USEPA of the report or its conclusions should be inferred.

This report has not been peer or administratively reviewed.

I. INTRODUCTION

The USEPA highway emission factor model, MOBILE5a, calculates average in-use emission factors for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) for eight categories of vehicles including heavy-duty gasoline (HDGV) and heavy-duty diesel (HDDV) vehicles (all vehicles with a gross vehicle weight of 8501 pounds or more). These emission factors are expressed in units of grams per mile (g/mi) and are used in combination with data on vehicle miles traveled (VMT) to estimate highway vehicle contributions to mobile source emission inventories. However, since emission standards for both gasoline and diesel heavy-duty vehicles are expressed in terms of grams per brake-horsepower-hour (g/bhp-hr), conversion factors in terms of brake-horsepower-hour per mile (bhp-hr/mi) must be used to convert the emission certification data from engine testing to in-use grams per mile. These conversion factors have been calculated several times over the last 15 years with the last update completed by EPA in 1988 for all heavy-duty vehicles [1][1].

The conversion factors used in MOBILE5a were calculated from the following expression:

$$\text{Conversion Factor (bhp-hr/mi)} = \frac{\text{Fuel Density (lb/gal)}}{\text{BSFC (lb/bhp-hr)} \times \text{Fuel Economy (mi/gal)}} \qquad \text{(I.1)}$$

where BSFC is brake-specific fuel economy.

There are two approaches for determining inputs to the above equation. One is to use brake specific fuel consumption (BSFC) and fuel economy for the in-use driving cycle to calculate the conversion factor. This would assume that the emissions factors in terms of grams of pollutant per unit work (g/bhp-hr) is only a function of the work required to move a truck or bus one mile, no matter how that mile is driven. This is clearly not the case for any of the pollutants as shown by Kitchen and Damico [2] and Brown et al. [3]. Kitchen and Damico studied several bus engines on both an engine dynamometer and in a bus on a chassis dynamometer over several different driving cycles. They found for all emissions that the conversion factors increased with increasingly heavier duty cycles. Brown et al. computed conversion factors for in-use class 8 heavy-duty trucks and found similar results.

The second approach is to use BSFC for the certification test cycle in which the emissions factors were generated and fuel economy for the in-use duty cycle. Historically, modelers have used BSFC from the certification test cycle because it was readily available from certification records. Dividing the emission rates by BSFC give emissions in terms of grams of pollutant per pound of fuel. As shown by Dreher and Harley [4], emissions generally vary less with duty cycle when expressed in these terms. Dividing this factor by fuel economy from the in-use driving cycle and multiplying by fuel density (as is done in the above equation) gives a more accurate conversion factor for different heavy-duty engine duty cycles. This is the approach that has been utilized in this study.

There are also some issues with the available fuel economy data for in-use trucks, namely the 1992 Truck Inventory and Use Survey (TIUS) [5]. If the fuel economy data represents a different

[1] Numbers in brackets refer to references in Section VII of this report.

driving cycle than is actually used on the road, there can be an error in the conversion factor calculated. This effect has been documented by Sierra Research [6].

The current TIUS data represents model year 1992 and earlier engines. However, the trend since the 1994 model year has been a large movement in diesel engines to sophisticated electronic control. These engines generally have a different NO_x-fuel economy trade-off than previous mechanically injected engines. Almost all on-highway diesel engines will be electronically controlled by 1998. Projecting conversion factors using older fuel economy data can present errors.

The conversion factors previously calculated for use in MOBILE5 and the ones calculated in this report are most likely only reasonable estimates of in-use NO_x emissions. Emissions of CO and particulates (PM) are less a function of the force required to drive a truck or bus (bhp-hr) than the frequency and severity of the transients in the duty cycle. While emissions of HC are not directly related to transients, they also are not a direct function of engine load. Having a different in-use duty cycle from the one used to generate emissions profiles on the engine dynamometer could result in very different conversion factors for each pollutant. This point was demonstrated for transit buses by Kitchen and Damico [2].

The best approach for determining conversion factors would be to develop in-use driving cycles and then test a statistically significant number of trucks and buses over those cycles to determine conversion factors for each pollutant and driving cycle. However, due to the significant resources required in terms of both time and money, and the limited availability of chassis dynamometer testing capability for heavy-duty trucks and buses, use of the present methodology employed in MOBILE5 as updated with newer data should, at least, provide reasonable estimates of in-use truck and bus NO_x emissions [6].

With the above caveats in mind, this report updates conversion factors used in MOBILE5 for all weight classes listed in Table 1. Since the most recent previous analysis and calculation of conversion factors [1] was based on actual data only through the 1986 model year, it is the purpose of this work to calculate conversion factors for model years 1987 through 1996 and project conversion factors from 1997 through 2050.

This report discusses the calculation of average engine brake-specific fuel consumption(BSFC) for model years 1987 through 1996 and calculates conversion factors for all weight classes listed in Table 1. In addition, it projects conversion factors for years 1997 through 2050. Calculation of fuel economy, non-engine fuel economy improvements and fuel density was detailed in a separate report [7].

II. CALCULATION OF CLASS SPECIFIC BSFCs by MODEL YEAR

To calculate average BSFCs for each category listed in Table 1, data on engine family specific BSFC for model years 1987 through 1996 were requested from eight engine manufacturers (three gasoline and five diesel). Six manufacturers supplied data for analysis. BSFCs for other manufacturers' engines were estimated using the data obtained from the six manufacturers for similar engines based upon the engine horsepower, engine specifications (determined from the engine family codes) and engineering knowledge of the various engine families. Engine family sales data for 1988 through 1995 was obtained from USEPA and used to weight the BSFCs. Sales data were first categorized into weight classes using manufacturer suggestions, engine horsepower and actual vehicle populations for each model year [8]. Engine family BSFCs were then weighted by sales fractions in each category listed in Table 1. BSFC for the certification cycle was used for all weight classes. Since the individual engine BSFCs and sales data was proprietary, it is not reproduced in this report.

Sales-weighted BSFC for all diesel truck weight classes, calculated as discussed above, are shown in Table 2. Sales-weighted BSFC for all gasoline truck weight classes are shown in Table 3. TIUS provided no data for class 8B gasoline trucks and therefore no BSFC or conversion factor for that class are calculated.

Table 1. Vehicle weight classes

Designation	Description	Gross Vehicle Weight (lb)
HDGV (class 2B)	Light heavy-duty gasoline vehicles	8501-10,000
HDGV (class 3)	Light heavy-duty gasoline vehicles	10,001-14,000
HDGV (class 4)	Heavy heavy-duty gasoline vehicles	14,001-16,000
HDGV (class 5)	Heavy heavy-duty gasoline vehicles	16,001-19,500
HDGV (class 6)	Heavy heavy-duty gasoline vehicles	19,501-26,000
HDGV (class 7)	Heavy heavy-duty gasoline vehicles	26,001-33,000
HDGV (class 8A)	Heavy heavy-duty gasoline vehicles	33,001-60,000
HDGV (class 8B)	Heavy heavy-duty gasoline vehicles	>60,000
HDGTB	Gasoline transit buses	all
HDGSB	Gasoline school buses	all
HDGCB	Gasoline intercity buses	all
HDDV (class 2B)	Light heavy-duty diesel trucks	8501-10,000
HDDV (class 3)	Light heavy-duty diesel trucks	10,001-14,000
HDDV (class 4)	Light heavy-duty diesel trucks	14,001-16,000
HDDV (class 5)	Light heavy-duty diesel trucks	16,001-19,500
HDDV (class 6)	Medium heavy-duty diesel trucks	19,501-26,000
HDDV (class 7)	Medium heavy-duty diesel trucks	26,001-33,000
HDDV (class 8A)	Heavy heavy-duty diesel trucks	33,001-60,000
HDDV (class 8B)	Heavy heavy-duty diesel trucks	>60,000
HDDTB	Diesel transit buses	all
HDDSB	Diesel school buses	all
HDDCB	Diesel intercity buses	all

In order to weight the BSFC data for bus engines, population data was taken from a number of sources. Transit bus engine populations for model years 1987 through 1995 were taken from the

APTA *1995 Transit Passenger Vehicle Fleet Inventory* [9] and are shown in Table 4 for diesel buses and Table 5 for gasoline buses. School bus counts of vehicle sizes for model years 1990 through 1996 were taken from *School Bus Fleet 1997 Fact Book* [10] and are shown in Table 6. Intercity bus diesel engine assumptions by model year based upon conversations with bus manufacturers are shown in Table 7. Gasoline intercity bus engines were assumed to be equally split among the "big three" gasoline engine manufacturers, Chrysler, Ford and General Motors. Population-weighted BSFCs for the three bus classes are shown in Table 8.

Table 2. Sales-weighted BSFC for diesel trucks
(lb/bhp-hr)

Model	Weight Class							
Year	2B	3	4	5	6	7	8A	8B
1988	0.553	0.544	0.478	0.465	0.444	0.414	0.403	0.395
1989	0.536	0.528	0.508	0.460	0.432	0.410	0.397	0.385
1990	0.545	0.535	0.504	0.453	0.432	0.397	0.397	0.375
1991	0.504	0.491	0.485	0.460	0.416	0.397	0.388	0.385
1992	0.494	0.491	0.450	0.450	0.450	0.395	0.400	0.407
1993	0.527	0.521	0.498	0.469	0.418	0.430	0.429	0.387
1994	0.516	0.500	0.490	0.444	0.431	0.415	0.392	0.371
1995	0.511	0.504	0.502	0.467	0.427	0.426	0.392	0.373

Table 3. Sales-weighted BSFC for gasoline trucks
(lb/bhp-hr)

Model	Weight Class						
Year	2B	3	4	5	6	7	8A
1988	0.611	0.626	0.642	0.640	0.642	0.640	0.638
1989	0.614	0.613	0.627	0.627	0.641	0.644	0.616
1990	0.607	0.610	0.611	0.607	0.638	0.639	0.621
1991	0.602	0.602	0.602	0.601	0.600	0.599	0.598
1992	0.588	0.595	0.604	0.606	0.602	0.600	0.600
1993	0.570	0.577	0.589	0.596	0.597	0.600	0.600
1994	0.570	0.587	0.608	0.607	0.604	0.602	0.600
1995	0.565	0.585	0.591	0.587	0.589	0.578	0.557

Table 4. Diesel transit bus inventory by engine type
(U.S. in-service population)

Model Year	DDC Series 50	6V-92	8V-92	Cummins L-10	Other Engines
1987		2189	33	355	238
1988		1826	5	683	142
1989		2983	102	239	96
1990		2910	34	1087	204
1991		1979	1	189	180
1992		1394	50	365	78
1993	257	1473	12	361	148
1994	1604	243	11	603	28
1995	1370	200		333	21

Table 5. Gasoline transit bus inventory by engine manufacturer (U.S. in-service population)

Model Year	Manufacturer Chrysler	Ford	GM
87		3	1
88	2		
89	1	12	
90		19	7
91		24	
92		7	
93		4	
94		36	3

Table 6. School bus inventory by bus type[2]
(U.S. in-service population)

	Diesel			Gasoline
MY	**A&B**	**C**	**D**	**A&B**
90	2225	23670	6286	3575
91	3756	21370	6864	3554
92	3820	16444	5444	2856
93	3535	18928	6734	3244
94	3215	21005	7321	3504
95	2216	20861	9671	3638
96	2225	22016	9270	3723

Table 7. Intercity diesel bus engine assumptions by model year
(% of U.S. in-service population)

Model	DDC			Cummins
Year	**Series 60**	**6V-92TA**	**8V-92TA**	**L-10**
1987		60%	30%	10%
1988		60%	30%	10%
1989		60%	30%	10%
1990		60%	30%	10%
1991		60%	30%	10%
1992		60%	30%	10%
1993	15%	60%	15%	10%
1994	50%	30%	10%	10%
1995	75%	15%		10%

[2] Types A & B are generally smaller school buses with the engine in the front. Types C and D are generally larger school buses, Type C has a front engine and Type D has an engine in the rear or midship.

Table 8. Sales- weighted bus BSFC (lb/bhp-hr)

Model Year	Diesel			Gasoline		
	Transit	Intercity	School	Transit	Intercity	School
1988	0.427	0.427		0.550	0.610	
1989	0.451	0.451		0.600	0.601	
1990	0.432	0.432	0.421	0.615	0.604	0.600
1991	0.438	0.438	0.420	0.598	0.595	0.595
1992	0.447	0.447	0.410	0.598	0.585	0.590
1993	0.440	0.440	0.407	0.541	0.569	0.585
1994	0.399	0.399	0.396	0.544	0.568	0.580
1995	0.402	0.407	0.391		0.569	0.575

A regression analysis was performed for BSFCs by model year for each weight class and a logarithmic curve (y = a + b*ln(x)) was used to extrapolate values prior to 1988 and after 1995[3]. These curves are shown in Table 9. Curve fit BSFCs for diesel trucks are shown in Table 10 and BSFCs used for determining conversion factors for 1987 in MOBILE5 [1] shown in Table 11. As shown by this comparison, the curve fits produced reasonable values when compared to MOBILE5 estimates.

Table 9. Curve fit equations for BSFCs by weight class and fuel

Class	Gasoline	Diesel
2B	y = -0.7211*ln(x) + 3.8473	y = -0.4806*ln(x) + 2.6959
3	y = -0.5656*ln(x) + 3.1535	y = -0.5183*ln(x) + 2.8529
4	y = -0.5583*ln(x) + 3.1319	y = -0.1780*ln(x) + 1.2897
5	y = -0.5435*ln(x) + 3.0630	y = -0.0349*ln(x) + 0.6162
6	y = -0.7339*ln(x) + 3.9284	y = -0.1706*ln(x) + 1.1985
7	y = -0.8224*ln(x) + 4.3266	y = -0.0863*ln(x) + 0.7854
8A	y = -0.7681*ln(x) + 4.0725	y = -0.1141*ln(x) + 0.9107
8B	N/A	y = -0.2003*ln(x) + 1.2858
Transit	y = -0.8652*ln(x) + 4.4842	y = -0.5058*ln(x) + 2.7092
Intercity	y = -0.4951*ln(x) + 2.8221	y = - 0.3648*ln(x) + 2.0764
School	y = -0.4648*ln(x) + 2.6918	y = -0.5311*ln(x) + 2.8123

y = BSFC (lb/bhp-hr)
x = MY - 1900

[3] Sales data was only available for model years 1988 through 1995.

Table 10. Curve fit diesel truck BSFC (lb/bhp-hr)

Model Year	Weight Class 2B	3	4	5	6	7	8A	8B
1987	0.550	0.538	0.495	0.460	0.437	0.400	0.401	0.391
1988	0.544	0.532	0.493	0.460	0.435	0.399	0.400	0.389
1989	0.539	0.526	0.491	0.460	0.433	0.398	0.399	0.387
1990	0.533	0.521	0.489	0.459	0.431	0.397	0.397	0.384
1991	0.528	0.515	0.487	0.459	0.429	0.396	0.396	0.382
1992	0.523	0.509	0.485	0.458	0.427	0.395	0.395	0.380
1993	0.518	0.504	0.483	0.458	0.425	0.394	0.394	0.378
1994	0.512	0.498	0.481	0.458	0.423	0.393	0.392	0.376
1995	0.507	0.493	0.479	0.457	0.422	0.392	0.391	0.374
1996	0.502	0.487	0.477	0.457	0.420	0.391	0.390	0.372

Table 11. MOBILE5 1987 diesel truck BSFC (lb/bhp-hr)

Weight Class 2B	3-5	6	7	8A	8B
0.54	0.51	0.45	0.44	0.41	0.39

Curve fit BSFCs for gasoline trucks are shown in Table 12 and estimated BSFCs from MOBILE5 for 1987 model year [1] are shown in Table 13. As shown by this comparison, these curve fits also produced reasonable values when compared to MOBILE5 estimates.

Curve fit bus BSFCs are shown in Table 14 for both diesel and gasoline buses for model years 1987 to 1996. BSFCs used for MOBILE5 conversion factors [1] for 1987 buses are shown in Table 15.

Table 12. Curve fit gasoline truck BSFCs (lb/bhp-hr)

Model	Weight Class						
Year	2B	3	4	5	6	7	8A
1987	0.627	0.628	0.638	0.636	0.651	0.654	0.642
1988	0.619	0.621	0.631	0.630	0.642	0.644	0.633
1989	0.611	0.615	0.625	0.624	0.634	0.635	0.625
1990	0.602	0.608	0.618	0.618	0.626	0.626	0.616
1991	0.595	0.602	0.612	0.612	0.618	0.617	0.608
1992	0.587	0.596	0.606	0.606	0.610	0.608	0.599
1993	0.579	0.590	0.600	0.600	0.602	0.599	0.591
1994	0.571	0.584	0.594	0.594	0.594	0.590	0.583
1995	0.563	0.578	0.588	0.588	0.586	0.581	0.575
1996	0.556	0.572	0.582	0.582	0.579	0.573	0.567

Table 13. MOBILE5 1987 gasoline truck BSFC (lb/bhp-hr)

Weight Class				
2B	3-5	6	7	8A
0.62	0.62	0.66	0.65	0.63

Table 14. Curve fit bus BSFCs (lb/bhp-hr)

Model	Diesel			Gasoline		
Year	Transit	Intercity	School	Transit	Intercity	School
1987	0.450	0.447	0.424	0.620	0.611	0.616
1988	0.445	0.443	0.423	0.610	0.605	0.611
1989	0.439	0.439	0.422	0.601	0.600	0.604
1990	0.433	0.435	0.421	0.591	0.594	0.600
1991	0.428	0.431	0.420	0.581	0.589	0.595
1992	0.422	0.427	0.411	0.572	0.583	0.590
1993	0.417	0.423	0.404	0.563	0.578	0.585
1994	0.411	0.419	0.398	0.553	0.573	0.580
1995	0.406	0.415	0.391	0.544	0.567	0.575
1996	0.401	0.411	0.384	0.535	0.562	0.570

Table 15. MOBILE5 1987 bus BSFC

(lb/bhp-hr)

Diesel			Gasoline		
Transit	**Intercity**	**School**	**Transit**	**Intercity**	**School**
0.479	0.467	0.444	--[a]	--[a]	0.660

[a] No sales were assumed for transit and school buses past 1980

BSFCs predicted for both diesel and gasoline buses had lower values than those used for calculation of conversion factors for MOBILE5. Since the transit bus information in MOBILE5 was based upon data for an older DDC 6V-92TA and a DDC 6V-71N, it is assumed that the newer more complete data on bus engine BSFC and in-use populations used in this analysis provide a more accurate picture of transit bus BSFC. While there is no mention of how BSFCs were calculated for other buses (intercity and school) in Machiele's report [1], it is also assumed that this analysis provided more complete data for those classes as well.

III. FUEL ECONOMY

Average truck fuel economy and use of non-engine fuel economy improvement devices were calculated using the 1992 Truck Inventory and Use Survey (TIUS) Microdata File [5]. Details of those calculations as well as bus fuel economy calculations can be found in Reference 7, which is a companion report for this work assignment. Curve fit diesel truck fuel economies are shown in Table 16. Fuel economies used for conversion factors in MOBILE5 for diesel trucks for 1987 (using 1992 estimated fuel economy and annual fuel economy improvement tables from Reference 1) are shown in Table 17. Average gasoline truck fuel economies from Reference 7 are shown in Table 18. MOBILE5 gasoline truck fuel economies for 1987 are shown in Table 19. Average bus fuel economies from Reference 7 are shown in Table 20 and MOBILE5 bus fuel economies for 1987 are shown in Table 21.

Estimated fuel economies for 1987 Class 2B diesel trucks derived in this study are significantly lower than the previous estimates used in MOBILE5. It is believed that this a result of TIUS not directly differentiating between Class 2A and Class 2B, and without doing an analysis similar to what was done for this study, higher mileage Class 2A vehicles would be averaged with lower mileage Class 2B vehicles. This study used vehicle weight to separate the two subclasses. The other difference in fuel economy (beyond the estimate in MOBILE5 that diesel vehicles in Classes 3-5 did not exist in this time period) is that the Class 8 trucks had better fuel economy than previously estimated in MOBILE5. A significant improvement in fuel economy has been seen in this class between 1982 and 1987 not previously accounted for in MOBILE5 estimates. Even though fuel economy was not calculated or used in this study beyond 1996, it is expected that fuel economy improvements due to electronic controls will result in even further improvements in fuel economy by 1998 in class 8 trucks.

Table 16. Diesel truck fuel economy taken from Reference 7 (miles per gallon)

Model Year	Weight Class 2B	3	4	5	6	7	8A	8B
1987	11.69	10.52	9.56	9.12	8.20	7.43	5.96	5.51
1988	11.83	10.65	9.63	9.21	8.25	7.44	6.03	5.59
1989	11.97	10.77	9.70	9.29	8.31	7.45	6.10	5.68
1990	12.11	10.90	9.77	9.38	8.37	7.46	6.17	5.77
1991	12.26	11.03	9.85	9.46	8.42	7.47	6.24	5.86
1992	12.40	11.15	9.92	9.54	8.48	7.48	6.31	5.95
1993	12.54	11.28	9.99	9.63	8.54	7.49	6.38	6.03
1994	12.68	11.41	10.06	9.71	8.59	7.51	6.45	6.12
1995	12.82	11.53	10.13	9.80	8.65	7.52	6.52	6.21
1996	12.96	11.66	10.20	9.88	8.71	7.53	6.59	6.30

Table 17. MOBILE5 1987 diesel truck fuel economy (miles per gallon)

Weight Class 2B	3-5	6	7	8A	8B
14.33	-- [a]	8.47	7.60	5.67	5.41

[a] No sales were assumed in classes 3-5 after 1976

Table 18. Gasoline truck fuel economy taken from Reference 7 (miles per gallon)

Model Year	Weight Class 2B	3	4	5	6	7	8A
1987	9.22	8.54	8.32	7.52	7.23	6.83	6.39
1988	9.32	8.63	8.43	7.58	7.33	6.89	6.47
1989	9.42	8.73	8.55	7.63	7.43	6.96	6.54
1990	9.52	8.82	8.66	7.68	7.53	7.03	6.62
1991	9.62	8.92	8.78	7.74	7.63	7.10	6.70
1992	9.73	9.01	8.89	7.79	7.73	7.17	6.77
1993	9.83	9.11	9.01	7.85	7.84	7.24	6.85
1994	9.93	9.20	9.12	7.90	7.94	7.31	6.92
1995	10.03	9.30	9.24	7.95	8.04	7.38	7.00
1996	10.13	9.39	9.35	8.01	8.14	7.45	7.07

Table 19. MOBILE5 1987 gasoline truck fuel economy

(miles per gallon)

Weight Class				
2B	**3-5**	**6**	**7**	**8A**
11.75	6.65	6.70	5.29	5.50

Table 20. Curve fit bus fuel economy from Reference 7
(miles per gallon)

Model	Diesel			Gasoline		
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

Table 21. MOBILE5 1987 bus fuel economy
(miles per gallon)

Diesel			Gasoline		
Transit	Intercity	School	Transit	Intercity	School
4.26	4.96	9.87	--[a]	--[a]	7.59

[a] No sales were assumed for transit and school buses past 1980

Gasoline truck fuel economies determined in this study were significantly higher that previous MOBILE5 estimates [1] (except for class 2B for the same reason as diesel class 2B trucks). Improved fuel economy in gasoline trucks since 1982 is due to improvements in fuel management and the introduction of electronic fuel injection which was not accounted for in MOBILE5 estimates.

Bus fuel economies determined in this study were significantly lower than previous MOBILE5 estimates [1] for both transit and school buses. It is assumed that the use of more up-to-date information on BSFCs and in-use populations used in this study provide a more accurate picture of bus fuel economy than was previously estimated for MOBILE5.

IV. FUEL DENSITIES

Fuel densities were determined from National Institute for Petroleum and Energy Research (NIPER) publications for both gasoline and diesel. Average gasoline density over the period 1987 through 1996 was 6.173 lb/gal [7] which compared well with the previous value of 6.09 lb/gal used in MOBILE5. Average diesel fuel density over the period 1987 through 1996 was 7.099 lb/gal [7] which compared well with the previous value of 7.11 lb/gal used in MOBILE5.

V. CALCULATION OF CONVERSION FACTORS

Using the equation defining the conversion factor in Section I together with the data described in Sections II, III and IV of this report, weight class specific conversion factors were calculated for gasoline and diesel vehicles for model years 1987 through 1996. Diesel truck conversion factors are shown in Table 22 with values developed for MOBILE5[4] shown in Table 23. Gasoline truck conversion factors are shown in Table 24 and corresponding conversion factors developed for MOBILE5 are shown in Table 25. Conversion factors for buses are shown in Table 26 with factors developed for use in MOBILE5 shown in Table 27.

Table 22. Diesel truck conversion factors (bhp-hr/mi)

Model Year	Weight Class							
	2B	3	4	5	6	7	8A	8B
1987	1.105	1.254	1.501	1.690	1.984	2.390	2.971	3.295
1988	1.103	1.253	1.496	1.676	1.979	2.392	2.946	3.263
1989	1.101	1.252	1.491	1.662	1.974	2.394	2.922	3.231
1990	1.099	1.251	1.486	1.649	1.969	2.396	2.898	3.201
1991	1.097	1.250	1.481	1.636	1.964	2.398	2.874	3.171
1992	1.095	1.250	1.476	1.623	1.960	2.400	2.851	3.141
1993	1.094	1.250	1.472	1.610	1.955	2.403	2.828	3.113
1994	1.093	1.250	1.467	1.597	1.951	2.405	2.806	3.085
1995	1.091	1.250	1.463	1.585	1.947	2.407	2.784	3.058
1996	1.090	1.250	1.458	1.573	1.942	2.409	2.763	3.031

Table 23. 1987 - 1996 diesel truck conversion factors developed for MOBILE5 (bhp-hr/mi)

[4] Actual conversion factors used in MOBILE5 are aggregated into one heavy-duty conversion factor for gasoline vehicles and one for diesel vehicles. Class specific conversion factors will be used in MOBILE6.

Weight Class							
2B	3	4	5	6	7	8A	8B
0.919	--[a]	--[a]	--[a]	1.865	2.127	2.987	3.129

[a] No sales were assumed in classes 3-5 after 1976

Table 24. Gasoline truck conversion factors (bhp-hr/mi)

Model Year	Weight Class 2B	3	4	5	6	7	8A
87	1.068	1.152	1.164	1.291	1.311	1.383	1.503
88	1.071	1.151	1.160	1.294	1.310	1.389	1.507
89	1.073	1.150	1.156	1.297	1.310	1.395	1.510
90	1.076	1.150	1.152	1.301	1.309	1.402	1.513
91	1.079	1.149	1.149	1.305	1.309	1.409	1.517
92	1.082	1.149	1.146	1.308	1.309	1.416	1.521
93	1.085	1.149	1.143	1.312	1.309	1.423	1.526
94	1.089	1.149	1.140	1.316	1.309	1.430	1.530
95	1.092	1.149	1.137	1.320	1.310	1.438	1.535
96	1.096	1.150	1.134	1.324	1.311	1.446	1.540

Table 25. 1987 - 1996 gasoline truck conversion factors developed for MOBILE5 (bhp-hr/mi)

Weight Class						
2B	3	4	5	6	7	8A
0.809	1.346	1.348	1.342	1.317	1.668	1.627

Table 26. Bus conversion factors (bhp-hr/mi)

Year	Diesel			Gasoline		
	Transit	Intercity	School	Transit	Intercity	School
87	4.595	3.422	2.661	3.195	2.779	1.622
88	4.602	3.415	2.673	3.210	2.773	1.628
89	4.609	3.408	2.685	3.225	2.767	1.633
90	4.617	3.402	2.697	3.241	2.762	1.639
91	4.625	3.395	2.708	3.258	2.757	1.645
92	4.635	3.390	2.771	3.275	2.752	1.651
93	4.645	3.384	2.823	3.294	2.747	1.658
94	4.655	3.379	2.877	3.313	2.743	1.664
95	4.667	3.374	2.932	3.333	2.739	1.671
96	4.679	3.370	2.989	3.354	2.735	1.677

Table 27. 1987-1996 bus conversion factors used in MOBILE5 (bhp-hr/mi)

Year	Diesel			Gasoline		
	Transit	Intercity	School	Transit	Intercity	School
96	3.241	2.890	1.615	--[a]	--[a]	1.161

[a] No sales were assumed for transit and school buses past 1980

Diesel truck conversion factors derived in this study matched MOBILE5 estimates within 10%. Gasoline truck conversion factors derived in this study tended to be lower than MOBILE5 estimates for Classes 3, 4, 7 and 8A due to the fuel economy improvement in those classes as shown by 1992 TIUS data. Both gasoline and diesel class 2B trucks in this study had a higher conversion factor than that used in MOBILE5 due to the lower fuel economy shown in TIUS when compared to the value used in MOBILE5. Bus conversion factors showed the greatest variation from MOBILE5 due to the much lower fuel economy estimated in this report than previously estimated for MOBILE5.

VI. PROJECTION OF CONVERSION FACTORS

Based upon the analysis in Reference 7, it is reasonable to assume that most of the non-engine fuel economy improvements available with current technology were already implemented in the U.S. fleet by the 1996 model year. Therefore, it is assumed that further fuel economy improvements will be associated with engine technology which will affect both BSFC and fuel economy. BSFC would decrease and fuel economy would increase, with these effects for the most part offsetting each other and thus having little impact in the calculated conversion factors. That being the case, conversion factors for projections beyond the 1996 model year should be similar to those for the 1996 model year.

Table 28 gives projected conversion factors for 1997 and later model years for diesel trucks. Projected conversion factors for 1997 and later model year gasoline trucks are shown in Table 29. Projected conversion factors for 1997 and later model year buses are shown in Table 30.

Table 28. Diesel truck conversion factor projections for 1997 and later model years (bhp-hr/mi)

Weight Class							
2B	**3**	**4**	**5**	**6**	**7**	**8A**	**8B**
1.090	1.250	1.458	1.573	1.942	2.409	2.763	3.031

Table 29. Gasoline truck conversion factor projections for 1997 and later model years (bhp-hr/mi)

Weight Class						
2B	**3**	**4**	**5**	**6**	**7**	**8A**
1.096	1.150	1.134	1.324	1.311	1.446	1.540

Table 30. Bus conversion factor projections for 1997 and later model years (bhp-hr/mi)

Diesel			Gasoline		
Transit	**Intercity**	**School**	**Transit**	**Intercity**	**School**
4.679	3.370	2.989	3.354	2.735	1.677

It should be noted that several unknowns can change these conversion factors in the future. The first is that changes in emissions control systems to meet future standards might change the ratio of fuel economy improvement to BSFC improvement. Second, there has been much debate over off cycle emissions in heavy-duty engines. As discussed in Section I, emissions can be significantly different for on-the-road operation than during the emissions certification test cycle. The last caveat is that these conversion factors are probably most reasonable for in-use NO_x emissions, since other emissions are more a function of transient behavior than the force required to move a truck or bus down the road.

VII. REFERENCES

1. P. Machiele, "Heavy-Duty Vehicle Emission Conversion Factors II - 1962-2000," EPA Technical Report EPA-AA-SDSB-89-01, October 1988.
2. M. Kitchen and W. Damico, "Development of Conversion Factors for Heavy-Duty Buses G/Bhp-Hr to G/Mile," EPA Technical Report EPA-AA-EVRB-92-01, July 1992.
3. J.E. Brown, D.B. Harris and F.G. King, "Comparison of Emission Models with On-Road Heavy-Duty Diesel Modal Data," NTIS PB98-116353, presented at the AWMA "Emission Inventory: Planning for the Future" conference, October 1997.
4. Dreher and Harley, "A Fuel-Based Inventory for Heavy-Duty Diesel Truck Emissions," Journal of the Air & Waste Management Association, April 1998.
5. "1992 Truck Inventory and Use Survey (TIUS) - Microdata File," U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, 1993 (on CD-ROM).
6. Memo from Phil Heirigs and Larry Caretto of Sierra Research to Mr. David Lax of American Petroleum Institute, May 20, 1997.
7. L. Browning, "Update of Heavy-Duty Engine Emission Conversion Factors -- Analysis of Fuel Economy, Non-Engine Fuel Economy Improvements and Fuel Densities," March 1998.
8. L. Browning, D. Coleman and C. Pera, "Update of Fleet Characterization Data for Use in MOBILE6," Acurex Environmental Report 97-105, May 1997.
9. "1995 Transit Passenger Vehicle Fleet Inventory as of January 1, 1995," American Public Transit Association, April 1995.
10. "School Bus Fleet -- 1997 Fact Book Issue," Bobit Publication Management & Maintenance Magazine for School Transportation Fleets, January 1997.