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Update of Heavy-Duty Emission Levels (Model Years 1988-2004+) for Use in MOBILE6

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Update of Heavy-Duty Emission Levels (Model Years 1988-2004+) for Use in MOBILE6

Final Report No. M6HDE.001

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Introduction

EPA intends to update the estimates of heavy-duty engine emission factors currently contained in MOBILE5b. To accomplish this, EPA plans to follow the same methodology employed in previous versions of the MOBILE model, using updated inputs. Succinctly, the methodology entails determination of a gram per mile (g/mi) emission factor by multiplying a work-specific emission level (in units of grams per horsepower-hour (g/bhp-hr)) by a conversion factor which converts work units into mileage units (bhp-hr/mi).

Emission Factor (g/mi) = Work-Specific Emission Level (g/bhp-hr) * Conversion Factor (bhp-hr/mi)

The conversion factors required for development of the g/mi emission factors will be detailed in another report. The purpose of this analysis is to develop updated work-specific emission levels necessary for computing heavy-duty emission factors for use in MOBILE6.

Background

EPA defines heavy-duty vehicles as those vehicles exceeding 8,500 lbs. gross vehicle weight (GVW). As noted in Table 1, this broad class of vehicles is divided into those requiring gasoline or diesel fuels, and is further subdivided into more specific classes based on GVW categories. EPA uses this more detailed subdivision scheme to account for different characteristics and general uses of the engines included in each GVW class.

Emissions of air pollutants from heavy-duty vehicles, particularly heavy-duty diesel vehicles, have come under increased scrutiny in recent years. This increased attention is due to three main factors: 1) EPA's past emphasis on control of emissions from passenger cars and light-duty trucks has effectively reduced the proportional contribution of these sources to mobile source air pollution, and hence has increased the relative significance of heavy-duty emissions; 2) the public has become increasingly concerned about the human health and environmental impacts of emissions of particulate matter and nitrogen oxides, both of which are emitted in relatively large amounts from heavy-duty diesel engines; and 3) advances in emission control technology have increased the cost effectiveness of regulating heavy-duty engines.

Table 1. Heavy-Duty Vehicle Classifications

Designation	Description	Gross Vehicle Weight (lbs.)
Gasoline Vehicles		
HDGV (classes 2B-3)	Heavy-duty gasoline vehicles	8,501-14,000
HDGV (classes 4-8)	Heavy-duty gasoline vehicles	>14,000
Diesel Vehicles		
HDDV (class 2B)	Light heavy-duty diesel trucks	8,501-10,000
HDDV (class 3)	Light heavy-duty diesel trucks	10,001-14,000
HDDV (classes 4-5)	Light heavy-duty diesel trucks	14,001-19,500
HDDV (classes 6-7)	Medium heavy-duty diesel trucks	19,501-33,000
HDDV (class 8A)	Heavy heavy-duty diesel trucks	33,001-60,000
HDDV (class 8B)	Heavy heavy-duty diesel trucks	>60,000
Urban Buses		
HDGB (school)	Heavy-duty gasoline school buses	all
HDGB (transit)	Heavy-duty gasoline transit buses	all
HDDB (school)	Heavy-duty diesel school buses	all
HDDB (transit)	Heavy-duty diesel transit buses	all

EPA has been regulating air pollutant emissions from heavy-duty gasoline and diesel vehicles since the 1970s. Since manufacturers of individual types of heavy-duty engines may sell these engines to multiple vehicle manufacturers for use in different applications (for both on-highway and off-highway vehicles), EPA has developed emission standards for heavy-duty *engines* instead of vehicles.

In response to the need to further reduce air pollution at the national level, EPA is currently in the process of finalizing a new set of combined emission standards for nitrogen oxides (NOx) and non-methane hydrocarbons (NMHC, hereafter referred to as HC) from heavy-duty engines, to become effective in model year 2004. Tables 2 and 3 list the emission standards for heavy-duty gasoline and heavy-duty diesel vehicles respectively since the mid-1980s, including the proposed new standard. Note that the 2004 standard applies to both heavy-duty gasoline and diesel vehicles, and is presented separately as NOx and HC .

Table 2. Emission Standards for New Heavy-Duty Gasoline Engines

Model Year	Pollutant (g/bhp-hr)			
	Hydrocarbons (HC)	Carbon Monoxide (CO)	Nitrogen oxides (NOx)	Particulate Matter (PM)
1987 (A)* (B)*	1.1 g/bhp-hr 1.9 g/bhp-hr	14.4 g/bhp-hr 37.1 g/bhp-hr	10.6 g/bhp-hr 10.6 g/bhp-hr	N/A
1988-1990 (A)* (B)*	1.1 g/bhp-hr 1.9 g/bhp-hr	14.4 g/bhp-hr 37.1 g/bhp-hr	6.0 g/bhp-hr 6.0 g/bhp-hr	N/A
1991-1997 (A)* (B)*	1.1 g/bhp-hr 1.9 g/bhp-hr	14.4 g/bhp-hr 37.1 g/bhp-hr	5.0 g/bhp-hr 5.0 g/bhp-hr	N/A
1998-2003 (A)* (B)*	1.1 g/bhp-hr 1.9 g/bhp-hr	14.4 g/bhp-hr 37.1 g/bhp-hr	4.0 g/bhp-hr 4.0 g/bhp-hr	N/A
2004	**2.5 g/bhp-hr combined NMHC + NOx	15.5 g/bhp-hr	**2.5 g/bhp-hr combined NMHC + NOx	N/A

***** (A) refers to heavy-duty gasoline engines less than 14,000 lbs. GVW.
(B) refers to heavy-duty gasoline engines greater than 14,000 lbs. GVW.
****** The 2004 standards apply to all GVW classes, and is defined as a combined non-methane hydrocarbon plus nitrogen oxides (NMHC + NOx) emission standard of 2.5 g/bhp-hr**.**

Table 3. Emission Standards for New Heavy-Duty Diesel Engines

Model Year	Pollutant (g/bhp-hr)			
	Hydrocarbons (HC)	Carbon Monoxide (CO)	Nitrogen oxides (NOx)	Particulate Matter (PM)
1985-1987	1.3 g/bhp-hr	15.5 g/bhp-hr	10.7 g/bhp-hr	None
1988-1989	1.3 g/bhp-hr	15.5 g/bhp-hr	10.7 g/bhp-hr	0.6 g/bhp-hr
1990	1.3 g/bhp-hr	15.5 g/bhp-hr	6.0 g/bhp-hr	0.6 g/bhp-hr
1991-1992	1.3 g/bhp-hr	15.5 g/bhp-hr	5.0 g/bhp-hr	0.25 g/bhp-hr
1993	1.3 g/bhp-hr	15.5 g/bhp-hr	5.0 g/bhp-hr	0.25 g/bhp-hr truck 0.10 g/bhp-hr urban bus
1994-1995	1.3 g/bhp-hr	15.5 g/bhp-hr	5.0 g/bhp-hr	0.10 g/bhp-hr truck 0.07 g/bhp-hr urban bus
1996-1997	1.3 g/bhp-hr	15.5 g/bhp-hr	5.0 g/bhp-hr	0.10 g/bhp-hr truck 0.05 g/bhp-hr urban bus
1998-2003	1.3 g/bhp-hr	15.5 g/bhp-hr	4.0 g/bhp-hr	0.10 g/bhp-hr truck 0.05 g/bhp-hr urban bus"
2004	**2.5 g/bhp-hr combined NMHC + NOx	15.5 g/bhp-hr	**2.5 g/bhp-hr combined NMHC + NOx	0.10 g/bhp-hr truck 0.05 g/bhp-hr urban bus"

****** The 2004 standards apply to all GVW classes, and is defined as a combined non-methane hydrocarbon plus nitrogen oxides (NMHC + NOx) emission standard of 2.5 g/bhp-hr**.**

In the above tables, one should note that heavy-duty gasoline emission standards are GVW-specific, while heavy-duty diesel emission standards apply to all GVWs. Also note that, for the most part, technical changes to engine design over the years were made in response to these emission standards. That is, engine design changes rather than emission control technology per se (e.g., catalytic converters, O_2 sensors) have been the primary means of compliance with heavy-duty engine emission standards to date.

Emissions Testing

Testing of heavy-duty vehicles to determine emissions may be performed in two ways. The first method involves removing the engine from the test vehicle's chassis (frame), mounting it on a test stand, and operating the engine on a testing apparatus known as an engine dynamometer. The second method involves testing the engine while it is still in the vehicle by operating the entire vehicle on what is known as a chassis dynamometer. The latter method is very similar to the approach used to test light-duty vehicle and light-duty truck emissions. Emission levels produced on the engine dynamometer are measured in grams per brake horsepower-hour (g/bhp-hr) or grams per kilowatt-hour (g/kW-hr) for a given test cycle, while emissions produced on a chassis dynamometer are measured in grams per mile (g/mi) or grams per kilometer (g/km). The results of these emissions tests are used to develop emission factors for heavy-duty vehicles that are then used in mobile source modeling and inventory development.

Both testing methods have certain limitations. Use of chassis dynamometers allows the investigator to directly account for the impacts of factors such as load and grade on emissions, thus providing a better sense of emissions due to real-world driving conditions. However, in-use emission factors for heavy-duty engines are more difficult to determine than for light-duty engines because chassis dynamometers capable of testing these heavy, larger vehicles are not widely available. Furthermore, manufacturers of heavy-duty engines may sell these engines for use in a variety of applications. Given these factors, the optimal test procedure for emission certification is testing the engine on an engine dynamometer.

Heavy-duty engine testing tends to be very costly. Due to the prohibitive costs involved in obtaining in-use emissions data on heavy-duty vehicles, very little recent test data existed at the time MOBILE5b, the latest version of the MOBILE model, was developed.. Therefore, the heavy-duty emissions factors in MOBILE5b (1996) are the same ones that were developed for use in MOBILE4 (1989). The 1980 through 1990 model year emissions factors are based on data derived from a cooperative test program between EPA and engine manufacturers, involving 18 heavy-duty gasoline engines (model years 1979 to 1982) and 22 heavy-duty diesel engines (model years 1979 to 1984). In MOBILE5b, emissions rates from the cooperative program were used unless the certification rate was higher than that produced from the test program. In cases were the certification results was greater, that rate was used instead.

Proposed Changes for MOBILE6

Since the release of MOBILE5b, very little new data on in-use heavy-duty engines, using representative driving cycles, has been produced. In lieu of actual data on in-use engines, EPA has proposed the use of test data required by EPA from engine manufacturers for new engine certification as a surrogate for in-use emissions data.

Under the EPA certification test procedure, manufacturers are required to submit emissions data on new engines using an engine dynamometer test. The engines are run on a transient engine dynamometer test cycle (developed from in-use data), and emission results are given in grams of pollutant per brake horsepower-hour.

Using this EPA engine dynamometer test cycle in the cooperative test program between EPA and engine manufacturers, the test results indicated that emission-control performance in heavy-duty vehicles does not suffer from significant deterioration. Given that these test data indicate that emission controls on these engines do not deteriorate greatly over time, and because the EPA engine dynamometer test cycle was developed to closely represent the in-use behavior of these engines, EPA assumed for this analysis that the emission levels produced by the certification test procedure are representative of the average in-use emission levels.

Methodology

Engine certification data consist of zero-mile level (ZML) emissions (new engine emissions) and rates of deterioration at the end of useful life, typically given in grams of pollutant per brake horsepower-hour (g/bhp-hr). For heavy-duty diesel engines, the certification data sets also generally include an intended service class for each engine model (light, medium, heavy, and bus). Useful life is defined as 110,000 miles for all heavy-duty gasoline engines and those engines with the intended service class of light heavy-duty diesel, 185,000 miles for medium heavy-duty diesel engines, and 290,000 miles for heavy heavy-duty diesel engines and buses.

Table 4. Intended service classes and useful lifetimes for heavy-duty engines

Engine Class	Gross Vehicle Weight (GVW) (lb)	Useful Life (miles)
All heavy-duty gasoline engines	8,501 - 60,000+	110,000
Light heavy-duty diesel engines	8,501 - 19,500	110,000
Medium heavy-duty diesel engines	19,501 - 33,000	185,000
Heavy heavy-duty diesel engines (incl. buses)	33,001 - 60,000+	290,000

The sum of the ZML and the deterioration rate must be less than the emission standard for each pollutant for the engine model to receive EPA certification. This is only true for each individual engine if no averaging, banking and/or trading provisions are used to offset excess emissions. For the purpose of modeling average, in-use emissions, these programs can be ignored.

For this analysis, the emission levels from the certification data were weighted by engine sales and rated power to produce average emission levels for gasoline and diesel-fueled heavy-duty engines, beginning with the 1988 model year and ending with 1995 model year data (the most current available during this analysis). This calculation was performed for ZML emissions as well as deterioration rates, and is illustrated by the following equation:

$$Emission\ Level\ (EL) = \frac{\sum (Sales_i * HP_i * EL_i)}{\sum (Sales_i * HP_i)}$$

A second method of averaging emission levels was identified; this method involve simply averaging emission level weighted by engine sales. However, EPA opted to use the method defined by the above equation because this method accounts for differences in rated power of various engine models, and also because the second method does not produce significantly different results from those calculated as stated above.

The above calculations were performed using certification and sales data for both gasoline and diesel heavy-duty engines by engine model year. Separate calculations were performed for hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). In addition to calculating average emission levels for all heavy-duty diesel engines, calculations were performed for each of the service classes as well. Heavy-duty gasoline engine certification reports do not include intended service class specification; therefore, a single average emission level for each model year is given.

There are several peculiarities within the certification data that must be noted by anyone working with the results provided in this report. Manufacturers often supply multiple emission results for a given engine family, because tests are often run on engines in the same engine family that are rated at different power levels. For this analysis, multiple results were averaged by emission level and rated power to avoid double counting the sales information. Another unusual characteristic of the certification data is that deterioration rates are sometimes given as multiples of the zero-mile emission rate and at other times as additive emissions to the zero-mile emission rate. The emission level results presented in this analysis account for these peculiarities and provide emission rates at the zero mile level and the incremental increase at the end of useful life.

A third caveat involves the reporting of deterioration rates in certification data reports. A

manufacturer is not permitted to report a negative deterioration. In cases where the manufacturer observed negative deterioration results, the certification report states that zero deterioration was found. Therefore, the average deterioration rates calculated from the certification data inflate the deterioration that the manufacturers have determined. And lastly, because all engines tested for certification meet the specifications of the manufacturer, the effects of engine malmaintenance and tampering on emissions are not included in the analysis.

Results of Analysis

Gasoline Engines

The certification data set for heavy-duty gasoline engines is sparsely populated. Close examination of the data sets seems to indicate that certification data for engine models which have been "carried over," or sold in subsequent years, have not been recorded in much of the certification data that EPA acquired for this analysis. This is especially true for the 1992 and 1993 data where only one major manufacturer's engines were reported for 1992 and another manufacturer's engines were reported for 1993. As it is quite unlikely that only one manufacturer sold heavy-duty gasoline engines in a given year, EPA assumes that this lack of sales and emission data is due to a reporting anomaly. This hypothesis is further supported by the fact that manufacturers of light-duty vehicles may not be required to re-certify models that carry-over; it is possible that the reporting assumptions were made in the heavy-duty gasoline database. Due to the data limitations, there is some concern as to the reliability of the emission level calculations derived from these data sets, particularly 1992 and 1993.

The results of the current analysis are compared to emission levels reported in MOBILE5b model. Tables 5, 6 and 7 present these comparisons for hydrocarbon, carbon dioxide, and nitrogen oxide emissions, respectively, by model year (1988 through 1995). Particulate matter emissions are not included here because gasoline engines generally produce negligible amounts of particulate. Model years 1992 and 1993 are in italics to signify the greater uncertainty involved with the calculations in these years, as explained above.

Table 5. Comparison of MOBILE5b and Certification Calculation Results for Emission Levels of Hydrocarbon from Heavy-Duty Gasoline Engines

Model Year	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/useful life)	
	MOBILE5b	Certification	MOBILE5b	Certification
1988	0.92	0.59	1.10	0.26
1989	0.92	0.65	1.10	0.24
1990	0.92	0.35	1.10	0.25
1991	0.92	0.30	1.10	0.21
1992	*0.92*	*0.32*	*1.10*	*0.27*
1993	*0.92*	*0.29*	*1.10*	*0.15*
1994	0.92	0.42	1.10	0.29
1995	0.92	0.38	1.10	0.23

Table 6. Comparison of MOBILE5b and Certification Calculation Results for Emission Levels of Carbon Monoxide from Heavy-Duty Gasoline Engines

Model Year	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/useful life)	
	MOBILE5b	Certification	MOBILE5b	Certification
1988	12.48	12.18	7.92	2.32
1989	12.48	15.65	7.92	3.12
1990	12.48	6.89	7.92	2.34
1991	12.48	6.11	7.92	1.95
1992	*12.48*	*6.59*	*7.92*	*4.35*
1993	*12.48*	*9.77*	*7.92*	*1.22*
1994	12.48	7.57	7.92	3.76
1995	12.48	7.69	7.92	3.50

Table 7. Comparison of MOBILE5b and Certification Calculation Results for Emission Levels of Nitrogen oxides from Heavy-Duty Gasoline Engines

Model Year	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/useful life)	
	MOBILE5b	Certification	MOBILE5b	Certification
1988	5.82	5.10	0.33	0.49
1989	5.82	4.82	0.33	0.48
1990	4.78	3.61	0.55	0.29
1991	3.99	3.52	0.55	0.34
1992	*3.99*	*3.13*	*0.55*	*0.62*
1993	*3.99*	*3.58*	*0.55*	*0.00*
1994	3.99	2.80	0.55	0.54
1995	3.99	2.79	0.55	0.56

Diesel Engines

The following four tables present the calculated emission level results from this analysis for hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter. Each table includes a total average emission level of the pollutant by model year (1988 through 1995), plus average emission levels by intended service class. For hydrocarbons, certification data for 1988 through 1994 was used; the certification data employed in the Regulatory Impact Analysis for the EPA Final Rulemaking entitled "Control of Emissions of Air Pollution from Highway Heavy-Duty Engines[1]" (containing projected sales) was used for this analysis for purposes of consistency.

For purposes of comparison, each table includes emission levels used by EPA's emission factor models, MOBILE5b and PART5. Note that MOBILE5b does not compute particulate matter emissions; therefore, for this analysis, results from EPA's separate particulate matter model, PART5, have been used.

Table 8. Modeled and Calculated Hydrocarbon Emission Levels for Heavy-Duty Diesel Engines

Model Year	Zero Mile Level (g/bhp-hr)						Deterioration (g/bhp-hr/useful life)					
	MOBILE 5b	Certification Data Calculations					MOBILE 5b	Certification Data Calculations				
	Modeled Total	Total	Heavy	Med.	Light	Bus	Modeled Total	Total	Heavy	Med.	Light	Bus
1988	1.03	0.56	0.42	0.67	0.74	NA	0.00	0.03	0.02	0.05	0.02	NA
1989	1.03	0.55	0.51	0.65	0.54	NA	0.00	0.02	0.02	0.04	0.02	NA
1990	1.03	0.52	NA	NA	NA	NA	0.00	0.01	NA	NA	NA	NA
1991	1.03	0.37	0.29	0.40	0.51	0.62	0.00	0.01	0.00	0.00	0.01	0.01
1992	1.03	0.45	0.21	0.52	0.25	NA	0.00	0.01	0.00	0.01	0.03	NA
1993	1.03	0.35	0.33	0.38	0.31	0.30	0.00	0.01	0.01	0.01	0.01	0.00
1994	1.03	0.26	0.22	0.31	0.26	0.11	0.00	0.01	0.02	0.00	0.01	0.01

Table 9. Modeled and Calculated Carbon Monoxide Emission Levels for Heavy-Duty Diesel Engines

Model Year	Zero Mile Level (g/bhp-hr)						Deterioration (g/bhp-hr/useful life)					
	MOBILE 5b	Certification Data Calculations					MOBILE 5b	Certification Data Calculations				
	Modeled Total	Total	Heavy	Med.	Light	Bus	Modeled Total	Total	Heavy	Med.	Light	Bus
1988	4.68	1.87	1.84	2.11	1.65	NA	1.16	0.38	0.34	0.44	0.40	NA
1989	4.68	0.94	0.84	1.28	0.78	NA	1.16	0.13	0.10	0.22	0.08	NA
1990	4.68	1.81	NA	NA	NA	NA	1.16	0.13	NA	NA	NA	NA
1991	4.68	1.32	1.81	1.22	0.28	2.70	1.16	0.11	0.08	0.25	0.00	0.00
1992	4.68	1.12	0.97	1.23	0.69	NA	1.16	0.05	0.00	0.04	0.07	NA
1993	4.68	1.56	1.85	1.29	0.98	2.90	1.16	0.12	0.08	0.16	0.22	0.00
1994	4.68	1.05	1.09	0.77	1.20	1.01	1.16	0.08	0.10	0.11	0.04	0.01
1995	4.68	1.09	1.05	0.98	1.19	1.12	1.16	0.10	0.10	0.22	0.01	0.01

Table 10. Modeled and Calculated Nitrogen Oxide Emission Levels for Heavy-Duty Diesel Engines

Model Year	Zero Mile Level (g/bhp-hr)						Deterioration (g/bhp-hr/useful life)					
	MOBILE 5b	Certification Data Calculations					MOBILE 5b	Certification Data Calculations				
	Modeled Total	Total	Heavy	Med.	Light	Bus	Modeled Total	Total	Heavy	Med.	Light	Bus
1988	7.93	6.0	6.47	6.64	4.38	NA	0.00	0.2	0.28	0.14	0.02	NA
1989	7.93	5.7	6.08	6.21	4.29	NA	0.00	0.2	0.27	0.18	0.02	NA
1990	5.64	4.9	NA	NA	NA	NA	0.00	0.1	NA	NA	NA	NA
1991	4.60	4.5	4.59	4.51	4.41	4.55	0.00	0.1	0.11	0.23	0.03	0.10
1992	4.60	4.5	4.46	4.57	4.06	NA	0.00	0.1	0.04	0.08	0.00	NA
1993	4.60	4.5	4.53	4.53	4.37	4.26	0.00	0.	0.11	0.06	0.01	0.00
1994	4.60	4.3	4.52	4.56	3.85	4.70	0.00	0.	0.12	0.01	0.00	0.01
1995	4.60	4.6	4.70	4.67	4.36	5.09	0.00	0.	0.05	0.03	0.01	0.01

Table 11. Modeled and Calculated Particulate Matter Emission Levels for Heavy-Duty Diesel Engines*

Model Year	Zero Mile Level (g/bhp-hr)						Deterioration (g/bhp-hr/useful life)					
	PART5	Certification Data Calculations					PART5	Certification Data Calculations				
	Modeled Total	Total	Heavy	Med.	Light	Bus	Modeled Total	Total	Heavy	Med.	Light	Bus
1988	~0.48	0.45	0.42	0.44	0.51	NA	0.00	0.02	0.02	0.04	0.01	NA
1989	~0.48	0.43	0.46	0.44	0.37	NA	0.00	0.02	0.02	0.02	0.01	NA
1990	~0.48	0.38	NA	NA	NA	NA	0.00	0.01	NA	NA	NA	NA
1991	~0.27	0.23	0.24	0.21	0.24	0.46	0.00	0.00	0.00	0.01	0.00	0.00
1992	~0.27	0.19	0.10	0.20	0.18	NA	0.00	0.01	0.00	0.01	0.00	NA
1993	~0.27	0.19	0.18	0.20	0.18	0.23	0.00	0.01	0.01	0.01	0.00	0.00
1994	~0.09	0.09	0.09	0.08	0.09	0.06	0.00	0.00	0.00	0.00	0.00	0.00
1995	~0.09	0.08	0.09	0.08	0.08	0.06	0.00	0.00	0.00	0.00	0.00	0.00

* The PART5 model uses slightly different but unique emission levels for various classes of trucks therefore an average level can be estimated for the assumed travel fraction of the different classes.

The certification data file for 1990 model year heavy-duty engines did not report different emissions for each of the three service classes or for buses. Therefore, EPA has only reported a total ZML and a total deterioration rate for this model year.

In most cases, the results of the calculations using the certification data are close to those being produced by the MOBILE5b and PART5 models. However, the modeled emission level estimates for HC and CO are higher than those produced by the certification data-based calculations.

Grams per brake-horse-power hour Emission Factors for Use in MOBILE6

After reviewing the results of the above calculations, EPA decided to re-compute the emission levels and deterioration rates based on specific model year groups. These model year groups represent changes in EPA emission standards.

Table 12. Model-year groups for heavy-duty gasoline engines, heavy-duty diesel engines and heavy-duty diesel buses for use in MOBILE6

Heavy-duty gasoline engines		Heavy-duty diesel engines		Heavy-duty diesel Buses	
Model Year Group	Regulatory Changes	Model Year Group	Regulatory Changes	Model Year Group	Regulatory Changes
1988-1989	10.7 g/bhp-hr NOx	1988-1989	10.7 g/bhp-hr NOx, 0.6 g/bhp-hr PM	1988-1989	6.0 g/bhp-hr NOx
1990	6.0 g/bhp-hr NOx	1990	6.0 g/bhp-hr NOx	1990	5.0 g/bhp-hr NOx
1991-1997	5.0 g/bhp-hr NOx	1991-1993	5.0 g/bhp-hr NOx , 0.25 g/bhp-hr PM	1991-1992	0.25 g/bhp-hr PM
1998-2003	4.0 g/bhp-hr NOx	1994-1997	0.10 g/bhp-hr PM	1993	0.10 g/bhp-hr PM (urban buses only)
2004+	2.5 g/bhp-hr HC + NOx	1998-2003	4.0 g/bhp-hr NOx	1994-1995	0.07 g/bhp-hr PM (urban buses only)
		2004+	2.5 g/bhp-hr HC + NOx	1996-1997	0.05 g/bhp-hr PM (urban buses only)
				1998-2003	4.0 g/bhp-hr NOx
				2004+	2.5 g/bhp-hr HC+NOx

By re-computing the averages based on these model year groups, we have attempted to reduced the impact of the data inconsistencies and caveats that were mentioned previously.

To improve the flexibility of MOBILE6's emission factors, EPA has opted to use the individual emission rates for each intended service class for heavy-duty diesels instead of a single emission rate. Since no separate intended service classes are defined for heavy-duty gasoline engines, EPA will continue to have a total emission rate in MOBILE6.

Projections for post-1995 model years were also computed. Tables presenting the re-computed ZMLs and deterioration rates, as well as explanations of the assumptions used in the projections, follow. All tables below present deterioration rates as g/bhp-hr/ 10,000 miles, for consistency with the MOBILE5b framework. Italicized emission rates are projections.

Heavy-Duty Gasoline Engine Inputs for MOBILE6

The heavy-duty gasoline zero mile levels and deterioration rates for HC, CO and NOx are presented below in Tables 13 through 15. Note that the heavy-duty gasoline engine emission rates and deterioration levels will also be applied to a separate heavy-duty gasoline bus category in the model.

HC projections are based on the assumption that no changes occur beyond the 1997 model year**.**

NOx projections for 1998+ are based on proportioning the emission rates calculated for 1991-1997 by a ratio of the standard in effect in 1998 (4.0 g/bhp-hr) to the standard in effect for the 1991-1997 model years (5.0 g/bhp-hr). This emission rate is carried through in the 2004+ projection as well.

Since no standard changes occurred between 1988 and 2004 for CO, EPA has assumed the same emission rate calculated in 1991-1997 for the 1998-2003 and 2004+ model year classes. All deterioration rates remain the same as in the 1991-1997 model year group.

Table 13. Heavy-duty Gasoline Engine Emission Rates for Hydrocarbons for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	MOBILE5b	Hydrocarbons	MOBILE5b	Hydrocarbons
1988-1989	0.92	0.62	0.10	0.023
1990	0.92	0.35	0.10	0.023
1991-1997	0.92	0.33	0.10	0.021
1998-2003	*0.92*	*0.33*	*0.10*	*0.021*
2004+	*0.92*	*0.33*	*0.10*	*0.021*

Table 14. Heavy-duty Gasoline Engine Emission Rates for Carbon Monoxide for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	MOBILE5b	Carbon Monoxide	MOBILE5b	Carbon Monoxide
1988-1989	12.48	13.84	0.72	0.246
1990	12.48	6.89	0.72	0.213
1991-1997	12.48	7.10	0.72	0.255
1998-2003	*12.48*	*7.10*	*0.72*	*0.255*
2004+	*12.48*	*7.10*	*0.72*	*0.255*

Table 15. Heavy-duty Gasoline Engine Emission Rates for Nitrogen Oxides for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	MOBILE5b	Nitrogen Oxides	MOBILE5b	Nitrogen Oxides
1988-1989	5.82	4.96	0.05	0.044
1990	5.82	3.61	0.05	0.026
1991-1997	3.99	3.24	0.05	0.038
1998-2003	*3.19*	*2.59*	*0.05*	*0.038*
2004+	*3.19*	*2.59*	*0.05*	*0.038*

Heavy-Duty Diesel Engine Inputs for MOBILE6

Zero mile levels and deterioration rates for HC, CO, NOx, and PM are presented for heavy-duty diesel engines in Tables 16 through 19. Since no standard changes have occurred for CO or PM during the 1988-2004+ period, emission projections are assumed to be the same as in the 1994-1997 model year class.

Due to the fact that HC emissions are quite low in the 1994-1997 model year group, EPA has assumed that engine manufacturers will not reduce HC emissions as a means of meeting the 0.5 g/bhp-hr NMHC + NOx emission standard that becomes effective in 2004**.** Therefore, emissions for 1998-2003 and 2004+ are assumed to be the same as in the 1994-1997 time frame**.**

For NOx, a ratio of 4.0 g/bhp-hr to 5.0 g/bhp-hr has been used to proportion the 1994-1997 emission rates as a means of projecting 1998-2003 emissions. Post-2004 rates are based on proportioning of the 1988-2003 rate by a ration of 2.0 g/bhp-hr to 4.0 g/bhp-hr, in the same manner as for heavy-duty gasoline vehicles.

Table 16. Heavy-duty Diesel Engine Emission Rates of Hydrocarbons for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)				Deterioration (g/bhp-hr/10,000 miles)			
	MOBILE5b	Heavy	Med.	Light	MOBILE5b	Heavy	Med.	Light
1988-1989	1.03	0.47	0.66	0.64	0.00	0.001	0.002	0.002
1990*	1.03	0.52	0.52	0.52	0.00	0.000	0.001	0.001
1991-1993	1.03	0.30	0.40	0.47	0.00	0.000	0.001	0.001
1994-1997	1.03	0.22	0.31	0.26	0.00	0.001	0.001	0.001
1998-2003	*1.03*	*0.22*	*0.31*	*0.26*	*0.00*	*0.001*	*0.001*	*0.001*
2004+	*1.03*	*0.22*	*0.31*	*0.26*	*0.00*	*0.001*	*0.001*	*0.001*

Table 17. Heavy-duty Diesel Engine Emission Rates of Carbon Monoxide for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)				Deterioration (g/bhp-hr/10,000 miles)			
	MOBILE5b	Heavy	Med.	Light	MOBILE5b	Heavy	Med.	Light
1988-1989	4.68	1.34	1.70	1.21	0.04	0.008	0.018	0.022
1990*	4.68	1.81	1.81	1.81	0.04	0.005	0.007	0.012
1991-1993	4.68	1.82	1.26	0.40	0.04	0.003	0.010	0.004
1994-1997	4.68	1.07	0.85	1.19	0.04	0.004	0.009	0.003
1998-2003	*4.68*	*1.07*	*0.85*	*1.19*	*0.04*	*0.004*	*0.009*	*0.003*
2004+	*4.68*	*1.07*	*0.85*	*1.19*	*0.04*	*0.004*	*0.009*	*0.003*

Table 18. Heavy-duty Diesel Engine Emission Rates of Nitrogen Oxides for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)				Deterioration (g/bhp-hr/10,000 miles)			
	MOBILE5b	Heavy	Med.	Light	MOBILE5b	Heavy	Med.	Light
1988-1989	7.93	6.28	6.43	4.34	0.00	0.010	0.009	0.002
1990*	5.64	4.85	4.85	4.85	0.00	0.004	0.006	0.011
1991-1993	4.60	4.56	4.53	4.38	0.00	0.004	0.007	0.003
1994-1997	4.60	4.61	4.61	4.08	0.00	0.003	0.001	0.001
1998-2003	*3.68*	*3.68*	*3.69*	*3.26*	*0.00*	*0.003*	*0.001*	*0.001*
2004+	*3.68*	*1.84*	*1.84*	*1.63*	*0.00*	*0.003*	*0.001*	*0.001*

Table 19. Heavy-duty Diesel Engine Emission Rates of Particulate Matter for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)				Deterioration (g/bhp-hr/10,000 miles)			
	PART5	Heavy	Med.	Light	PART5	Heavy	Med.	Light
1988-1989	~0.48	0.44	0.44	0.44	0.00	0.001	0.002	0.001
1990*	~0.48	0.38	0.38	0.38	0.00	0.000	0.000	0.000
1991-1993	~0.27	0.21	0.20	0.23	0.00	0.000	0.001	0.000
1994-1997	~0.09	0.08	0.08	0.09	0.00	0.000	0.001	0.000
1998-2003	*~0.09*	*0.08*	*0.08*	*0.09*	*0.00*	*0.000*	*0.000*	*0.000*
2004+	*~0.09*	*0.08*	*0.08*	*0.08*	*0.00*	*0.000*	*0.000*	*0.000*

Heavy-duty diesel buses engines

Projections for buses essentially follow the same pattern as heavy-duty diesels, with standard changes for HC and NOx occurring in the years for which projections were made. However, there is one exception. In 1994, separate standards were implemented for particulate matter from buses. In 1994, the bus PM standard was 0.07 g/bhp-hr. This standard was changed to 0.05 g/bhp-hr in 1996. This ratio was used to project PM emissions for the 1996-1997 heavy-duty diesel bus category. Projections for PM emissions beyond 1997 are assumed to be the same as in 1996-1997.

Table 20. Heavy-duty Diesel Bus Engine Emission Rates of Hydrocarbons for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	MOBILE5b	Hydrocarbons	MOBILE5b	Hydrocarbons
1988-1989	1.03	0.47	0.00	0.001
1990	1.03	0.52	0.00	0.000
1991-1992	1.03	0.62	0.00	0.000
1993	1.03	0.30	0.00	0.000
1994-1995	1.03	0.08	0.00	0.000
1996-1997	*1.03*	*0.08*	*0.00*	*0.000*
1998-2003	*1.03*	*0.08*	*0.00*	*0.000*
2004+	*1.03*	*0.08*	*0.00*	*0.000*

Table 21. Heavy-duty Diesel Bus Engine Emission Rates of Carbon Monoxide for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	MOBILE5b	Carbon Monoxide	MOBILE5b	Carbon Monoxide
1988-1989	4.68	1.34	0.04	0.001
1990	4.68	1.81	0.04	0.005
1991-1992	4.68	2.7	0.04	0.000
1993	4.68	2.9	0.04	0.000
1994-1995	4.68	1.06	0.04	0.000
1996-1997	*4.68*	*1.06*	*0.04*	*0.000*
1998-2003	*4.68*	*1.06*	*0.04*	*0.000*
2004+	*4.68*	*1.06*	*0.04*	*0.000*

Table 22. Heavy-duty Diesel Bus Engine Emission Rates of Nitrogen Oxides for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	MOBILE5b	Nitrogen Oxides	MOBILE5b	Nitrogen Oxides
1988-1989	7.93	6.28	0.00	0.000
1990	5.64	4.85	0.00	0.004
1991-1992	4.60	4.55	0.00	0.000
1993	4.60	4.26	0.00	0.000
1994-1995	4.60	4.88	0.00	0.000
1996-1997	*4.60*	*4.88*	*0.00*	*0.000*
1998-2003	*3.68*	*3.90*	*0.00*	*0.000*
2004+	*3.68*	*1.95*	*0.00*	*0.000*

Table 23. Heavy-duty Diesel Buses Emission Rates of Particulate Matter for Use in MOBILE6

Model Year Class	Zero Mile Level (g/bhp-hr)		Deterioration (g/bhp-hr/10,000 miles)	
	PART5	Particulate Matter	PART5	Particulate Matter
1988-1989	~0.48	0.44	0.000	0.001
1990	~0.48	0.38	0.000	0.000
1991-1992	~0.27	0.46	0.000	0.000
1993	~0.27	0.23	0.000	0.000
1994-1995	~0.09	0.06	0.000	0.000
1996-1997	~0.09	*0.04*	*0.000*	*0.000*
1998-2003	~0.09	*0.04*	*0.000*	*0.000*
2004+	~0.09	*0.04*	*0.000*	*0.000*

Altitude Adjustment Factors

The MOBILE6 model will calculate emission factors for eight heavy-duty gas truck categories, eight heavy-duty diesel truck categories, one heavy-duty gasoline bus category and two heavy-duty diesel bus categories in two regions (low- and high- altitude) of the country. Low-altitude emission factors are based on conditions representative of approximately 500 feet above mean sea level and high-altitude emission factors represent conditions of approximately 5,500 feet above sea level.

To update the altitude-specific adjustment factors, EPA sought available test data for heavy-duty gasoline vehicles and heavy duty diesel vehicles at "low" and "high" altitude. The following sections describe the data sources used to determine altitude adjustment factors and the resulting emission rates.

Heavy-duty Gasoline Vehicles Altitude Adjustment Factors

At the time of this analysis, EPA was unable to obtain recent studies relaying the effects of varying altitude on exhaust emissions from heavy-duty gasoline vehicles. Therefore, MOBILE6 will apply the same altitude adjustment factors for heavy-duty gasoline vehicles that were used in MOBILE5. The high altitude adjustment factors for heavy-duty gasoline vehicles are listed below in Table 24.

Table 24 Heavy-duty Gasoline Vehicle High Altitude Adjustment Factors for HC, CO, and NOx

	Altitude Adjustment Factors		
Model Year	**Hydrocarbons**	**Carbon Monoxide**	**Oxides of Nitrogen**
1987 and later	1.855	3.182	0.818

Heavy-duty Diesel Vehicle Altitude Adjustment Factors

EPA was only able to locate a small number of studies evaluating the effects of altitude changes on emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen, and particulate matter. These studies are listed in Table 25, and full citations are provided in the bibliography. To develop new altitude adjustment factors for heavy-duty diesel vehicles in MOBILE6, EPA calculated the difference between the emission rate at the reported low altitude and the emission rate at the high altitude, and averaged the results from all of the studies. Note that there was some variability in the altitudes used for testing; however, EPA deemed these differences and their effects on the reported emission levels to be negligible and used all of the available data. The average difference between low altitude and high altitude will be used in MOBILE6 for all heavy-duty categories to characterize the effect of altitude changes on emissions. Table 25 lists reported low-and high altitude emission rates, the average emission rates, and the altitude adjustment factors for heavy-duty diesel vehicles.

Table 25 Heavy-duty Diesel Vehicle High Altitude Adjustment Factors for HC, CO, NOx, and PM

Data Source	Report Year	Engine Type	Model Year	HC		CO		NOx		PM		Test Altitude	
				Low	High	Low	High	Low	High	Low	High	Low	High
EPA Report EPA-68-03-4044 [2]	1989	EPA Caterpillar 3208	1980	0.90	3.76	5.48	20.90	9.63	8.59	0.63	1.30	500	6000
EPA Report EPA-68-03-4044	1989	EPA Cummins NTC-350	1984	0.95	1.14	2.37	4.47	5.21	4.83	0.47	0.68	500	6000
ES&T Volume 31 #4 [3]	1998	DDC Series 60	1989	0.14	0.15	2.80	4.01	8.00	5.13	0.42	0.25	500	5280
NFRAQS[4]	1998	DDC Series 50 6047GK28DD2	1993	0.10	0.04	0.90	3.13	4.70	5.88	0.08	0.13	500	5280
NFRAQS	1998	DDC Series 50 6047GK28DD3	1993	0.10	0.05	0.90	3.51	4.70	8.88	0.08	0.10	500	5280
NFRAQS	1998	Navistar DTA-466 E250	1993	0.30	0.20	0.90	1.95	4.50	4.43	0.22	0.23	500	5280
SAE Report #940669[5]	1994	DDC Series 60	1994	0.09	0.14	2.77	4.42	4.44	4.39	0.21	0.32	800	5540
SAE Report #961166[6]	1996	DDC Series 60	1991	0.10	0.16	2.20	4.46	4.70	4.64	0.13	0.30	500	5280
SAE Report #961974[7]	1996	DDCSeries 50	1995	0.10	0.06	1.60	2.24	4.65	4.97	0.08	0.10	500	5280
		Average Emission Rate:		0.31	0.63	2.21	5.45	5.61	5.75	0.26	0.38		

ALTITUDE ADJUSTMENT FACTORS **HC** 2.05 **CO** 2.46 **NOx** 1.02 **PM** 1.47

ES&T=Environmental Science & Technology
NFRAQS=Northern Front Range Air Quality Study
SAE= Society of Automotive Engineers
(a) Data represents estimate emissions trends with altitude for technologies that comply with 1991 U.S. EPA Standards
(b) Data represents estimate emissions trends with altitude for technologies that comply with 1994 U.S. EPA Standards
(c) Data represents emission trends with altitude for 1984 model year California turbocharged and aftercooled engines

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