United States Environmental Protection Agency
Air and Radiation
EPA420-R-03-001
January 2003
M6.PM.001

MOBILE6.1 Particulate Emission Factor Model Technical Description

Final Report

Printed on Recycled Paper

EPA420-R-03-001
January 2003

MOBILE6.1 Particulate Emission Factor Model Technical Description

Final Report

M6.PM.001

Edward L. Glover
Mitch Cumberworth
Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

1. Introduction

Since 1995, EPA has made available the PART5 model, a Fortran program that estimates particulate air pollution emissions of in-use gasoline-fueled and diesel-fueled highway motor vehicles. It calculates particle emission factors in grams per mile (g/mi) for on-road automobiles, trucks, and motorcycles, for particle sizes of 1-10 microns. The particulate matter (PM) estimates include emission factors for exhaust particulate, brakewear, and tirewear. The PART5 model is now outdated.

MOBILE6 is the most recent EPA emission factor computer model. It calculates in-use fleet emission factors for three criteria pollutants: hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). These emission estimates are made for gas, diesel and natural gas fueled cars, trucks, buses and motorcycles for calendar years 1952 through 2050. The model calculates emission factors under a wide variety of conditions affecting in-use emission levels, e.g., ambient temperatures, average traffic speeds, etc.

MOBILE and PART5 have been used by EPA and other organizations in a variety of applications. These include evaluations of highway mobile source control strategies by state, local and regional planning agencies; emission inventories and control strategies for State Implementation Plans under the Clean Air Act; transportation plans and conformity analyzes by metropolitan planning organizations and state transportation departments; environmental impact statements by industry investigators; and academic research efforts.

This document describes the methodology and algorithms used to combine PART5 and MOBILE6 to produce an integrated MOBILE6.2 model. This new model produces the same estimates for HC, CO and NOx emission as MOBILE6.0, but it also can estimate particulate emission factors like the PART5 model. The MOBILE6.2 particulate emission estimates differ somewhat from the PART5 estimates. The principal reasons for these differences are changes in vehicle registration and technology distributions between PART5 and MOBILE6 and the fact that some particulate emission rates for future model years have been updated in MOBILE6.2 to reflect recent rule-makings.

2. Overview of MOBILE6.2 Features

The MOBILE6.2 model offers several advantages relative to the separate MOBILE6.0 and PART5 models. First, the combination eliminates significant duplication of technical material between the two models. For instance, both models contain many of the same data parameters relating to vehicle activity and use. Both models also have very similar input requirements and produce similar output. Second, combining the two models aids users who are now given a single, consistent interface for both functions, and allows EPA to support one consistent computer model product rather than two. Combining PART5 and MOBILE6.0 was a prominent recommendation *of Modeling MOBILE SOURCE Emissions*, the National Academy of Science Research Council's review of MOBILE. This panel concluded that the process of emission inventory modeling could be improved by creating a new model or suite of integrated models that could produce emission factor estimates for a wider range of pollutants and conditions.

The objective of the MOBILE6.2 update from PART5 was to produce, in the relatively short term, a combined model that reflects EPA particulate emission modeling done for recent vehicle emission control rule-makings. The project takes into account the fuel sulfur level reductions that are now mandated, and new vehicle emission standards.

Originally, it was EPA's intention to update the basic PM emission factors as part of the MOBILE6.2 development process. We looked at several test programs that collected particulate matter data on both light-duty gasoline vehicles and heavy-duty diesel vehicles. We also looked carefully at the California vehicle emission factor model - EMFAC7, and we did some limited analysis of the available data. After careful consideration, EPA decided that the test programs were not sufficient to allow us to do a comprehensive and scientifically credible update to the basic particulate emission factors that could be applied to the nation as a whole. On the heavy-duty diesel vehicle side, there were only small data sets collected from numerous sources. Also, the vehicles in the test samples tended to be low mileage trucks. These issues prevented EPA from making a credible projection of in-use emission function that would be any different from the one made in the PART5 model, and the 2007 Heavy-Duty Diesel rule-making support documents. On the light-duty gasoline vehicle side, some of the problems included inconsistent test programs that emphasized new vehicles, and the inability to accurately quantify the effects and number of vehicles that produce excessive amount of smoke and particulates.

To get the data that is needed to revise the existing particulate emission factors, EPA is undertaking major test programs in cooperation with CRC, CARB, EIIP, NREL and DOT to update the particulate matter emission estimates for heavy-duty diesels and light-duty gasoline vehicles. Once these data are available, it is our intention to do a rigorous analysis of the data and make the results available in the new EPA MOVES emission model.

Until the new data have been collected and thoroughly analyzed, the foundation of MOBILE6.2 is made up of the basic mobile source particulate emission rates from the PART5 model, and from the EPA rule-making modeling sources. These sources are supported by a large body of engine and vehicle certification test results, and from some limited in-use test programs.

One of the new features of MOBILE6.2 is its ability to accept alternative basic exhaust particulate rates into the model as a function of vehicle class, model year, catalyst technology, and vehicle age. Deterioration estimates as a function of mileage can also be added. This new feature allows new or alternate emission factors to be entered into the model without reprogramming. Changes are merely made to the existing external data files that accompany the model.

Section 3 (Technical Description) describes the way PART5 and MOBILE6.0 were combined to produce MOBILE6.2 and the new features added. Here is a brief summary of these updates:

2.1 **<u>Base Emission Rates</u>** - The base emission rates for most vehicle classes and model years are unchanged from PART5. However, the basic emission rates for heavy-duty diesel vehicles were updated in MOBILE6.2 to reflect the emission factors modeled in EPA's 2007 Heavy-Duty Diesel Vehicle Rule-making effort. As a result MOBILE6.2 predicts that 2007 and later model year diesel heavy-duty vehicles will meet a 0.01 g/bhp-hr certification standard if low sulfur fuel is used. The basic PM emission rates for light-duty and heavy-duty gasoline vehicles were updated to assume compliance with EPA's Tier2 vehicle rule-making requirements in 2004, and with the 2005 heavy-duty gasoline vehicle rule-making, if low sulfur fuel is used.

2.2 **Sulfate Particulate and Gaseous SO2 Emission Factors** - PART5's calculation of sulphate particulate and gaseous SO2 exhaust emissions were restructured to account for the sulfur levels of gasoline and diesel fuel, while still using the same basic algorithms as PART5. This feature of the program now allows the user to model the effects of different fuels and changes in EPA fuel regulations.

2.3 **Ammonia Emission Factors** - MOBILE6.2 adds the ability to estimate exhaust emissions of ammonia. These estimates are based on the emission rates and calculation methods described in EPA Report Number EPA/AA/CTAB/PA/81-20, entitled "Determination of a Range of Concern for Mobile Source Emissions of Ammonia". While this report dates from 1981, we are not aware of a better or significantly different basis for such calculations.

2.4 **ZEVs** - MOBILE6.2 allows the user to model the effects of zero emitting vehicles on particulate emissions whereas PART5 did not have this capability. In MOBILE6.2 the exhaust particulate emission factors are assumed to be zero for ZEVs. However, their tire and brake wear emissions are assumed to be the same as gasoline-fueled vehicles.

2.5 **Natural Gas Vehicles (NGVs)**

PART5 did not contain exhaust particulate emission estimates for NGVs. MOBILE6.2 assumes that the exhaust particulate emissions of NGVs are the same as gasoline-fueled vehicles operating on very low sulfur fuel. This assumption is based on comparisons between NGV and gasoline vehicle hydrocarbon emission test results. These test results, provided by the NGV industry (See EPA report EPA420-R-01-033) suggest that NGVs generally have equivalent or lower emissions than gasoline vehicles. Based on the similarity between hydrocarbon and particulate emission formation, the general assumption of rough equivalence between these vehicle types was extended to their particulate emission factors. The tire and brake wear emissions of NGVs are assumed to be the same as gasoline-fueled vehicles.

Further improvements to the estimation of mobile source particulate emissions will be made in the course of the longer term effort to produce a new generation of mobile source air pollution models (MOVES). The MOVES model is intended to implement the recommendations of the National Academy of Science. It will be based on an extensive database of emission measurements made during actual operation of in-use vehicles and will provide a framework for allocating emission estimates to much smaller geographic areas and time periods.

3. Technical Description

3.1 Definitions

The MOBILE6.2 model reports separate PM emission factors for twenty-eight vehicle classes covering model years 1952 through 2050. The PM and PM-related pollutants are:

OCARBON - The organic carbon portion of diesel exhaust particulate emissions. It was denoted as SOF in the PART5 model.

ECARBON - The elemental carbon and residual carbon portion of diesel vehicle exhaust particulate. It was denoted as RCP in the PART5 model.

Sulfate - The sulfate particulate emissions. These are based directly on the sulfur content of the fuel.

Lead - The lead particulate emissions. These are based directly on the quantity of lead in the automotive fuel. Like PART5, MOBILE6.2 model assumes that post 1975 model year vehicles and all calendar years subsequent to 1991 are free from lead PM emissions.

Total Exhaust Diesel PM = OCARBON + ECARBON + Sulfate + Lead

In MOBILE6.2, Total Exhaust Diesel PM is calculated by the model and then apportioned to the four reported constituents: OCARBON, ECARBON, Sulfate, and Lead.

GASPM - The sum of the organic and elemental carbon portion and any residual carbon portion of gasoline vehicle exhaust particulate.

Total Exhaust Gasoline PM = GASPM + Sulfate + Lead

In MOBILE6.2, Total Exhaust Gasoline PM is the sum of three constituents GASPM, Sulfate and Lead emissions.

NH3 - Ammonia emission factors. These are new to the MOBILE6 and PART5 model series. Ammonia is a gaseous pollutant that is converted in the atmosphere to an ammonium based particulate emission. Only the gaseous emissions which are directly emitted from a vehicle tailpipe are reported by MOBILE6.2. The model does not contain any algorithms pertaining to the conversion of gaseous emissions to particulate emissions. These reactions and their effects are calculated in other EPA models.

BRAKE - Particulate emission factors from Brake wear.

TIRE - Particulate emission factors from Tire wear.

SO2 - Gaseous Sulfur Dioxide Emissions. These are based directly on the fuel sulfur content.

The emission factors listed above are reported by vehicle type. The 28 vehicle types are listed and described in Table 3.1. They are the same classifications used in MOBILE6.0. This is an expansion from the twelve vehicle classifications that the PART5 model used, but each PART5 vehicle class corresponds directly to one or to a group of MOBILE6.2 vehicle classes.

Table 3.1
MOBILE6 Vehicle Classifications

Number	***MOBILE6 Abbreviation***	***Description***	***PART5 Abbreviation***
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)	LDGV
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)	LDGT1
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,001 lbs. GVWR, 3,751-5750 lbs. LVW)	LDGT1
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8500 lbs. GVWR, 0-5750 lbs. ALVW)	LDGT2
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8500 lbs. GVWR, 5,751 and greater lbs. ALVW)	LDGT2
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8501-10,000 lbs. GVWR)	HDGV
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)	HDGV
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)	HDGV
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)	HDGV
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)	HDGV
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)	HDGV
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)	HDGV
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)	HDGV
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)	LDDV
15	LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)	LDDT
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8501-10,000 lbs. GVWR)	2BHDDV
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)	LHDDV
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)	LHDDV
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)	MHDDV
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)	MHDDV
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)	MHDDV

22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)	HHDDV
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)	HHDDV
24	MC	Motorcycles (Gasoline)	MC
25	HDGB	Gasoline Buses (School, Transit and Urban)	BUSES
26	HDDBT	Diesel Transit and Urban Buses	BUSES
27	HDDBS	Diesel School Buses	BUSES
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)	LDDT

3.2 Calculation of Particulate Emission Constituents

3.2.1 Calculation of Organic Carbon (OCARBON) Emissions

The pollutant type called OCARBON in MOBILE6.2 was formerly called Soluble Organic Fraction (SOF) in PART5. This type of particulate emission is generally a complex mixture of organic chemical matter that is attached to the ‘carbon’ core of the particle. As the former name implies, it is soluble in some organic solvents. The name was changed to OCARBON in the model because it was felt that the former name (soluble organic fraction) was less precise and misleading (i.e., soluble in which solvent? and the output is in terms of grams per mile not a fraction or percentage).

Other than the name change, no changes from PART5 were made in the definition of the pollutant, or in the values of OCARBON-related parameters in the associated calculation algorithm. The algorithm and data parameters presented here are used to model all diesel vehicle classes for all model years. Due to a lack of consistent and reliable data, gasoline vehicle particulate emission factors are not broken out into OCARBON and ECARBON, but are reported as GASPM.

For diesel vehicles, the organic carbon emissions are calculated by first subtracting the sulfate and lead emission factors from the total exhaust PM emission factor. The remainder is then multiplied by the organic carbon fractions (OCFRAC) to produce the OCARBON emission factor. The values of OCFRAC are the same as in the PART5 model. The algorithm is shown mathematically in Equation 3.1.

```
OCARBON   =   [Exh PM - Sulfate - Lead] * OCFRAC         Eqn 3.1
```

The values of OCFRAC are a function of the vehicle class. The following values were taken directly from PART5.

Vehicle Class Number	Vehicle Type	OCFRAC
14	LDDV	0.18
15	LDDT1, LDDT2	0.50
28	LDDT3, LDDT4	0.48
16	2b	0.51
17 and 18	3 and 4	0.51

19,20,21, 26 and 27	5 through 7, buses	0.44
22 and 23	8a and 8b	0.24

3.2.2 Calculation of Elemental Carbon (ECARBON) Emissions

The pollutant type called ECARBON or elemental carbon in MOBILE6.2 was formerly called Remaining Carbon Portion (RCP) in PART5. As the former name implies it is the 'elemental carbon' portion of the particulate after all other constituents have been removed. Other than the name change no changes were made in the definition of the pollutant. The algorithm presented here is used to model all diesel vehicle classes for all model years. Gasoline vehicle particulate emission factors are not broken out into OCARBON and ECARBON, but are reported only as the sum GASPM. The elemental carbon emissions are calculated by subtracting the sulfate, lead and OCARBON emissions from the total Exhaust Particulate Emission factor. The algorithm is shown mathematically in Equation 3.2.

```
ECARBON = [total diesel exhaust PM - Sulfate -
                           OCARBON - lead]                Eqn 3.2
```

3.2.3 Calculation of LEAD Emissions

The lead emission factors are based directly on the quantity of lead in the automotive fuel. The model assumes that all post-1975 model year vehicles that were not tampered with and all calendar years subsequent to 1991 are free from lead PM emissions. The algorithm and data coefficients used to calculate LEAD emissions are the same as those used in the PART5 model. The frequency of leaded fuel tampering effects (rates of tampering) are the same as those used in MOBILE6.0. The PART5 documentation contains a thorough explanation of these calculations. [DRAFT User's Guide to PART5: A Program for Calculating Particle Emissions from Motor Vehicles - EPA-AA-AQAB-94-2, pp 48-52.]

3.2.4 Calculation of BRAKE-WEAR Emissions

The PM brake wear emission factor was not updated from PART5. [See PART5 User Guide page 63.] The brake wear emission factor is assumed to be the same for all vehicle classes in the model. It is set equal to:

```
BRAKE     =    0.0128 * PSBRK                             Eqn 3.3
```

where

PSBRK = The fraction of particles less than or equal to the particle size cutoff

3.2.5 Calculation of TIRE-WEAR Emissions

The tire wear emission factor in units of grams per mile was not updated from PART5. It is given by equation 3.4. This equation is used for all vehicle classes and model years.

```
TIRE =    0.002 * PSTIRE * WHEELS                              Eqn 3.4
```

where

TIRE is the emission factor in grams per mile
PSTIRE is the fraction of particles less than or equal to the particle size cutoff.
WHEELs is the number of wheels on a vehicle class.

The value of 0.002 is the emission rate of airborne particles from tire wear [taken from Compilation of Air Pollutant Emission Factors, Volume 2,: Stationary Point and Area Sources. EPA (AP-42, 4th Edition)].

The tire wear emission factors are the same as those used in PART5 with one exception. In MOBILE6.2, number of wheels on a School Bus has been increased to 6 from 4 (the analogous brakewear number does not change because the number of brake disks or drums is not increased by the addition of two wheels).

3.2.6 Calculation of Sulfate and Gaseous Sulfur Dioxide Emissions

The methodology for calculating sulfate and gaseous sulfur dioxide emissions (SO2) is based on PART5. [See PART5 User Guide - EPA-AA-AQAB-94-2 pp 50 to 60]. PART5 did not have user inputs for gasoline or diesel fuel sulfur levels. MOBILE6.2 has user-supplied fuel sulfur levels and has extended the PART5 algorithm to use them.

The overall methodology for calculating sulfate particulate and SO2 emissions in MOBILE6.2 is based on the principal of sulfur conservation and mass balance. This means that the sulfur contained in the gasoline or diesel fuel must be equal on a mass basis to the sulfur leaving in the exhaust stream as sulfate and gaseous SO2 emissions. The proportion of the fuel sulfur that is converted to either sulfate or gaseous SO2 emissions is discussed below.

3.2.6.1 Calculation of Gasoline Vehicle Sulfate Emissions

The gasoline vehicle sulfate emissions are a function of catalyst availability, catalyst type, air injection availability, speed and vehicle fuel economy. The calculations require three parameters: the basic sulfate emission rates (which depend on speed), the technology weighting factors (air injection type, catalyst type, etc.), and the fuel economy values. The basic sulfate emission factors (Table 3.4 Sulfate Emission values) were taken from the PART5 model, and are not updated for MOBILE6.2. The vehicle fleet technology weighting factors were taken from MOBILE6.0 and are slightly different than those used in PART5. The fuel economy values were also taken from the MOBILE6.0 model, and are slightly different than those used in PART5.

Basic Sulfate Emission Factors

The basic gasoline vehicle sulfate emission factors for all model year gasoline vehicles are shown in Tables 3.2 and 3.3. All emission factors except the Sulfate emission slope (sulfate emissions versus fuel sulfur level) were taken from PART5 [See PART5 user guide]. The sulfate emission factors are a function of catalyst type, air injection type and average speed bin. Two speed bins are shown in the table: 19.6 MPH and 34.8 MPH. Sulfate emission levels at intermediate speeds are calculated by linear interpolation between these two speeds. Speeds below 19.6 MPH are considered to be 19.6 MPH and speeds above 34.8 are considered to be 34.8 for this purpose.

The tables contain two columns of emission values. The first value is the sulfate emission factor in grams per mile at a fuel sulfur level of 340 ppm sulfur (0.034 wt%). This value was taken from PART5 and represents the fuel sulfur level of the underlying emission tests for all gasoline vehicles. The second ‘slope’ value is the sulfate emission rate as a function of the fuel sulfur level in units of [grams/mile] per ppm Sulfur. These were calculated from a linear interpolation of the 340 ppm sulfur point, and the 0 ppm sulfur point. Logically, the 0 ppm gasoline fuel sulfur level will produce zero sulfate emissions.

As a result of the Tier2 rule-making for 2004 and later model years, the 340 ppm fuel sulfur level is no longer representative of in-use vehicle fuel for these model year vehicles. Thus, the base sulfate emission factors used in pre-Tier2 vehicles are unrepresentative as well. Unfortunately, there is also no new test data at a lower sulfur fuel level such as 30 ppm in which to develop new sulfate emission factors. To overcome this lack of representative data, the pre-2004 model year sulfate emission factors were ratioed down to the 30 ppm sulfur level using the ‘Slopes’ in Table 3.2 (also shown in Table 3.3). These resulting sulfate levels based on 30 ppm fuel sulfur and shown in Table 3.3 then become the basis for the 2004 and later model year gasoline vehicles rather than the sulfate emission factors shown in Table 3-2.

In the MOBILE6.2 model the gasoline sulfur effects in Tables 3-2 and 3-3 are extrapolated linearly to a maximum of 1000 ppm gasoline fuel sulfur levels (600 ppm maximum sulfur in gasoline fuel for 2000 and later model years). (The linear sulfur function was used because no data were available to develop any other functional response.) This approximation has only a minimal impact on MOBILE6.2's total exhaust PM emission estimates.

Table 3-2
Gasoline Vehicle Sulfate Emission Factors
thru Model year 2003

Technology Type	Speed BIN	Sulfate Emission (g/mi) @340 ppm Sulfur	Sulfate Emission (g/mi*ppm S) SLOPE
Non Catalyst	< 19.6 MPH	0.002	5.882e-6
Ox Cat/No Air	< 19.6 MPH	0.005	1.471e-5
3W Cat/No Air	< 19.6 MPH	0.005	1.471e-5
Ox Cat / Air	< 19.6 MPH	0.016	4.706e-5
3W Cat/ Air	< 19.6 MPH	0.016	4.706e-5
Non Catalyst	> 34.8 MPH	0.001	2.941e-6
Ox Cat/No Air	> 34.8 MPH	0.005	1.471e-5
3W Cat/No Air	> 34.8 MPH	0.001	2.941e-6
Ox Cat / Air	> 34.8 MPH	0.020	5.882e-5
3W Cat / Air	> 34.8 MPH	0.025	7.353e-5

Table 3-3 Gasoline Vehicle Sulfate Emission Factors Model Years 2004 and Later			
Technology Type	**Speed BIN**	**Sulfate Emission (g/mi) @30 ppm Sulfur**	**Sulfate Emission (g/mi*ppm S) SLOPE**
Non Catalyst	< 19.6 MPH	0.0002	5.882e-6
Ox Cat/No Air	< 19.6 MPH	0.0004	1.471e-5
3W Cat/No Air	< 19.6 MPH	0.0004	1.471e-5
Ox Cat / Air	< 19.6 MPH	0.0014	4.706e-5
3W Cat / Air	< 19.6 MPH	0.0014	4.706e-5
Non Catalyst	> 34.8 MPH	0.0001	2.941e-6
Ox Cat/No Air	> 34.8 MPH	0.0004	1.471e-5
3W Cat/No Air	> 34.8 MPH	0.0001	2.941e-6
Ox Cat / Air	> 34.8 MPH	0.0018	5.882e-5
3W Cat / Air	> 34.8 MPH	0.0022	7.353e-5

Gasoline Sulfate Emission Technology Weighting Factors

The gasoline sulfate emission factors shown in Tables 3.2 and 3.3 by technology type are combined into a composite all technology factor based on the technology weighting factors already present in the MOBILE6.0 model. Equation 3.5 is the general equation used to calculate these.

```
Sulfate   =    SUM[EF(i) * Frac(i)]                    Eqn 3.5
```

Where EF(i) are the sulfate emission factors in Table 3-2 dn 3-3, Frac(i) are the technology fractions, and indexing by ‘i’ represents summation over the technology categories and MOBILE6 vehicle speed bins. The technology fractions are functions of vehicle type and model year that are calculated in MOBILE6.2 based on vehicle technology distributions already present in MOBILE6.0. The technology fraction topic is discussed in detail in EPA report M6.FLT.008A.

3.2.6.2 Calculation of Gasoline Vehicle SO2 Emissions

The model assumes that all of the sulfur in the fuel is exhausted either as sulfate emissions or gaseous sulfur dioxide emissions (SO2). Thus, once the sulfate emissions are calculated, the remaining sulfur in the fuel is considered to be exhaust SO2.

The first step in this calculation is to determine the fraction of the gasoline fuel sulfur that is converted to sulfate emissions (DCNVRT). This is done by using the gasoline fuel sulfur relationship from PART5 shown in Equation 3.6. A value of DCNVRT is calculated for each of the technology and speed groups.

```
DCNVRT = Sulfate * FE / [UNITS * (1.+WATER) * FDNSTY *SWGHT ]          Eqn 3.6
```

Where:

DCNVRT - percent of sulfur in the fuel that is directly converted to sulfate.
Sulfate - is the direct sulfate emission factor of a vehicle in g/mi calculated from Table 3.4a or Table 3.4b.
WATER - is the constant 1.2857 (see PART5 User Guide).
FDNSTY - is the fuel density. It is a constant value of 6.09 lb/gal.
FE - is the fuel economy in miles per gallon. (These values come from MOBILE6). They are a function of model year and vehicle class.
SWGHT - is the weight percent of sulfur in the fuel. (i.e., 0.034 = 340 ppm gasoline fuel sulfur).

UNITS - is the constant 13.6078. This is the units conversion factor. Calculated by (453.592 * 3)/100. Where 453.592 is the number of grams in a pound, 3 is the weight ratio of SO4 to sulfur, and the 100 is to correct for the weight percent of sulfur.

The gaseous SO2 emissions are calculated as in PART5 by plugging the values of DCNVRT into the SO2 emission equation (Eqn 3.7), and solving for SO2 for each technology and speed group.

```
SO2 = UNITS#2 * FDNSTY * SWGHT * (1. - DCNVRT) / FE        Eqn 3.7
```

Where:

UNITS#2 = 9.072. This is the units #2 conversion factor. Calculated by (453.592 * 2)/100. Where 453.592 is the number of grams in a pound, 2 is the weight ratio of SO2 to sulfur, and the 100 is to correct for the weight percent of sulfur.

The final composite SO2 emission factor is calculated by weighing together the individual technology and speed SO2 emission factors. The same weighting factors are used for both Sulfate and SO2 emissions.

Mathematically, it is shown in Equation 3.8.

```
Composite SO2  =    SUM[SO2(i) * Frac(i)]                 Eqn 3.8
```

Where SO2(i) are the emission factors calculated in the gaseous SO2 Equation X, Frac(i) are the technology fractions, and indexing by i represents that the summation is over the technology types and MOBILE6 speed bins.

3.2.6.3 Gasoline Vehicle Sulfate and SO2 Emission Sample Calculation

This section provides a sample calculation for the gasoline fueled vehicle sulfate and SO2 emission factors for two technology and speed groups (no weighting factors will be used). It is provided to give the reader a feel for the relative size of the Sulfate and gaseous SO2 emission factors.

```
Sulfate emission conversion:
Speed Bin > 34.8 MPH

DCNVRT = Sulfate * FE / [UNITS * (1.+WATER) * FDNSTY *SWGHT ]

DCNVRT    =    (0.001 g/mi * 25 mile/gal) /
               [ 13.6078 * (1+1.2857) * 6.09 lb/gal * 0.034%

DCNVRT    =    0.00384 or 0.39% for the 3-way catalyst no air pump
               group.

DCNVRT    =    0.0970 or 9.70% for the 3-way catalyst with air
               pump group.

Gaseous SO2 Emissions:

SO2 = UNITS#2 * FDNSTY * SWGHT * (1. - DCNVRT) / FE

SO2  =    9.072 * 6.09 lb/gal * 0.034% * (1-0.00384) / 25

SO2  =    0.0748 g/mi for the 3-way catalyst no air pump group at
          340 ppm gasoline fuel sulfur.
```

3.2.6.4 Calculation of Diesel Vehicle Sulfate Emissions

The diesel vehicle sulfate emissions are a function of the basic user supplied diesel fuel sulfur level (a required input for PM emission calculation in MOBILE6.2), and the diesel vehicle fuel economy values. The fuel economy values currently in use for the for diesel vehicles were taken from the MOBILE6 emission model. Future versions of the MOBILE6 model (Version MOBILE6.3) may contain updated fuel economy estimates and allow user input of alternative values.

Sulfate emissions are calculated for diesel fueled vehicles in MOBILE6.2 by using Equation 3.9.

Sulfate = UNITS * (1.+WATER)*DFDNSTY*DWGHT*DCNVRT / FE   Eqn 3.9

Where:

Sulfate is the direct sulfate emission factor of a vehicle in g/mi.
WATER is the constant 1.2857.
DFDNSTY is the constant 7.11 lb/gal.
FE is the fuel economy in miles per gallon. (These values are to come from MOBILE6). They are a function of model year and vehicle class.
DWGHT weight percent of sulfur in the fuel. (i.e., 0.050 = 500 ppm diesel fuel sulfur).
DCNVRT percent of sulfur in the fuel that is directly converted to sulfate. MOBILE6.2 retrains the 2% value of this parameter from PART5.
UNITS is the constant 13.6078.

Sulfate emissions for diesel vehicles are calculated using the assumption from PART5 that 2 percent of the sulfur in the diesel is converted into sulfate compounds, and the remaining sulfur is converted to SO2 compounds.

3.2.6.5 Calculation of Diesel Vehicle Gaseous SO2 Emissions

The diesel vehicle gaseous SO2 emissions are calculated using equation 3.10. The methodology assumes that the 98 percent of the fuel sulfur is converted to gaseous SO2 emissions. Like the calculation for the diesel vehicle sulfate emissions, the gaseous SO2 emissions are a function of user input fuel sulfur level and the vehicle fuel economies.

```
SO2 = UNITS#2 * FDNSTY * SWGHT * (1. - DCNVRT) / FE      Eqn 3.10
```

3.2.6.6 Diesel Sulfate Emissions on Vehicles with Particulate Trap Technology

It is anticipated that future technology needed to meet strict particulate matter standards for diesel vehicles in model years 2007 and later will include particulate traps. Such traps may take a variety of designs; however, the basic principle is for the trap to collect virtually all of the particulate matter present in the exhaust stream, and to either burn it off at high temperature or to otherwise remove it from the exhaust stream. Currently, no data exist as to efficiency of this process nor do any sulfate emission factor data exist to suggest the magnitude of such emissions. Thus, the model will set in calendar years 2007 and later, a very low base diesel fuel sulfur level of 10 ppm as required in the Heavy-Duty 2007 Rule, and continue to predict that, fleet-wide, 2 percent of this fuel stream is emitted as sulfate emissions.

3.2.7 Calculation of Total Exhaust PM Emissions

3.2.7.1 Diesel Vehicles

Total Exh PM Calculation

The general equation for total exhaust particulate emissions is shown in Eqn 3.10b. It includes OCARBON, ECARBON and Sulfate emissions. Calculation details on these sub-components have been previously discussed in Sections 3.2.6.1 through 3.2.6.6.

```
Total Exh PM   = OCARBON + ECARBON + Sulfate       Eqn 3.10b
```

The default total exhaust particulate emission rates are represented as a linear function with respect to mileage. For the light-duty diesel vehicles the rates were taken from the PART5 model (See EPA report EPA-AA-AQAB-94-2). The default total exhaust particulate parameters for heavy-duty diesel vehicles are also a linear function, and are shown in the MOBILE6.0 technical support materials - see EPA reports M6.HDE.001, M6.HDE.002, and M6.HDE.004. They can also be found in the support materials section of the EPA 2007 heavy-duty rule making docket.

The total exhaust PM emission rates in MOBILE6.2 are a function of vehicle class (all diesel classes can have a separate emission factor), model year (1950 - 2020+), and mileage. The mileage relationship is linear with a zero mile emission level, two possible slopes and a user supplied inflection point between the two slopes (Equation 3.11).

```
Exh PM = ZML + DET1*mileage1 + DET2(mileage2-mileage1)  Eqn 3.11a
```

The default values of these parameters are provided in the Excel Spreadsheets PMDZML.csv, PMDDR1.csv and PMDDR2.csv. Examination of the heavy-duty emission rates in these spreadsheets shows that in virtually all cases the zero mile emission level is assumed to be the certification standard, and the deterioration rates with respect to mileage are zero.

Total Exh PM Size Correction Factors

The total exhaust PM emission factors are computed on the basis of the entire amount of PM material that is collected on an EPA test filter during the emission tests. This is referred to as PM30. Exh PM calculated in Eqn 3.11a is in terms of PM30.

For use in the MOBILE6.2 model, the particulate emissions must be converted from PM30 terms into particulate size terms that can range from PM1 to PM10. The general equation for any size in the range of 1 micron to 10 microns (x) for this transformation is given in Eqn 3.11b.

```
Exh PM(x) =    Exh PM(30) * SIZE CF                        Eqn 3.11b
```

This value is not allowed to exceed the certification standard applicable to future years if future rule-makings are being modeled.

The values for the SIZE CF used in Eqn 3.11b are shown in Table 3.4. Correction factors are provided for the range of pollutant type, vehicle/fuel classes and particle sizes. Linear interpolation should be used to calculate correction factors for particle sizes between those listed in Table 3.4.

Table 3.4
Fraction of Particulate Mass Less than or Equal to the Particle Size Cutoff

Vehicle Type/ Particulate Component	Particle Size Cutoff (PSC)	Fraction of Particles less than or Equal to the Particle Size Cutoff
Gasoline vehicles using leaded fuel/ Lead, Carbon	10.0	0.64
	2.0	0.43
	0.2	0.23
Gasoline vehicles with catalyst, using unleaded fuel/ Lead, Carbon	10.0	0.97
	2.0	0.89
	0.2	0.87
Gasoline vehicles without a catalyst, using unleaded fuel/ Lead, Carbon	10.0	0.90
	2.0	0.66
	0.2	0.42
Diesel vehicles/ Exhaust PM	10.0	1.00
	2.5	0.92
	2.0	0.90
	1.0	0.86
All vehicles/ Brake-wear	10.0	0.98
	7.0	0.90
	4.7	0.82
	1.1	0.16
	0.43	0.09
All vehicles/ Tire-wear	10.0	1.00
	0.10	0.01

Reference:

"Size Specific Total Particulate Emission Factors for Mobile Sources", EPA 460/3-85-005

Calculation of OCARBON and ECARBON

The total exhaust particulate emission factor corrected for particulate size (Exh PM) calculated in Equation 3.11b is substituted into Equations 3.12 and 3.13 (rewrites of Equation 3.1 and 3.2 where lead is zero for diesel vehicles) to calculate OCARBON and ECARBON emission factors. The appropriate sulfate emission factors corrected for particulate size are also substituted into the two equations to account for these constituents. The sulfate emission factor is the "base" diesel fuel sulfur level 'Sulfate[b]'. For pre-2007 model years this base level is 500 ppm sulfur. For 2007+ it is 8 ppm sulfur. It is subtracted from the OCARBON and ECARBON emission factors

```
C_OCARBON = [C_EXH_PM - Sulfate[b]] * OCFRAC                Eqn 3.12

C_ECARBON = [C_EXH_PM - Sulfate[b] - OCARBON]               Eqn 3.13
```

3.2.7.2 Gasoline Vehicles

The GASPM emission factors are supplied as a function of vehicle class, catalyst technology, model year (1950 - 2020+), and mileage. The mileage relationship is linear with a zero mile emission level, two possible slopes and a user supplied inflection point between the two slopes (Equation 3.14). The default values of these parameters are provided in Excel Spreadsheets PMGZML.csv, PMGDR1.csv and PMGDR2.csv.

```
GASPM = ZML + DET1*mileage1 + DET2(mileage2-mileage1)    Eqn 3.14
```

The default particulate parameters (zero mile and deterioration rates) are taken from PART5 values for gasoline vehicles (See EPA report EPA-AA-AQAB-94-2). As a result, in all cases the deterioration rates DET1 and DET2 are assumed to be zero.

The sulfate emission factors for gasoline vehicles are calculated according to the equations discussed in Section 3.2.6.1. The calculated sulfate emission factor is based on the user specified fuel sulfur level [i] rather than on the "base" level at which original emission factor testing was done. The lead emission factors are calculated according to the algorithm referenced in Section 3.2.3. They are a function of technology, model year, existence of tampering and calendar year. They cannot be changed by the user.

The Exhaust PM emission factor for gasoline vehicles is the sum of the GASPM, sulfate and lead emission factors, and is shown mathematically in Equation 3.15.

```
Exhaust PM (gas vehicles) = GASPM + sulfate[i] + lead    Eqn 3.15
```

Like the diesel vehicles, the Exhaust PM emission factor for gasoline vehicles is compared against the certification standard level and capped at this level if it exceeds it. This will typically not happen except in the case of the 2004+ Tier2 emission vehicles which have stringent PM standards.

The Total Exhaust PM emissions for gasoline vehicles are also adjusted for particle size using a particle size distribution function. These particle size correction factors are taken directly from PART5 and are tabulated in the PART5 User Guide. Mathematically, the calculation is shown in Equation 3.16.

```
Total Exhaust PM    = Exhaust PM * Particle Size Corr    Eqn 3.16
```

3.3 Ammonia Emission Calculations

3.3.1 Ammonia Emission Factors

The MOBILE6.2 model calculates a composite, FTP test based (composite running and start emissions) gaseous ammonia emission factor for all vehicle types and model years. The base ammonia emission factors built into the MOBILE6.2 model were taken from the EPA report EPA/AA/CTAB/PA/81-20 "Determination of a Range of Concern for Mobile Source Emissions of Ammonia" by Robert Garbe, August, 1981. They can also be found in SAE paper 830987. They were selected for use in MOBILE6.2 because of their established use in EPA's National Trends modeling for many years, and a lack of new ammonia emission test results. Because the emission factors are about 20 years old, a literature search was conducted to verify that they are still representative of current vehicles. A description of this literature search is contained in Appendix A.

The ammonia emission factor values used in the MOBILE6.2 model are shown in Table 3.5. All units are milligrams per mile.

Table 3.5 **Ammonia Emission Factors by Vehicle Class and Catalyst Type** Intercept Values in Regression **(all UNITS are Milligrams per Mile)**				
MOBILE6 Vehicle Types	All	Non Catalyst	Ox Catalyst	3-Way Catalyst
1 - 5 (LDG)		11.265 mg/mi	15.128 mg/mi	101.711 mg/mi
24 (MC)	11.265 mg/mi			
6 - 13, 25 (HDG)	45.062 mg/mi			
14, 15, 28 (LDD)	6.759 mg/mi			
16 - 23, 26, 27 (HDD)	27.037 mg/mi			
LDG are the light-duty gasoline vehicles MC is the motorcycle class HDG are the heavy-duty gas vehicles LDD are the light-duty diesel vehicles HDD are the heavy-duty diesel vehicles.				

Based on the literature search, EPA concluded that these numbers are in the same general range as the limited FTP test results, and thus are appropriate for use in MOBILE6.2. However, there is substantial variation in ammonia measurements and ammonia is likely a function of sulfur level, test cycle (FTP versus US06), advancing catalyst technology, and other factors. Additional research is recommended on this topic.

The gaseous ammonia emission factors are reported by the MOBILE6.2 model in the particulate section because gaseous ammonia reacts with sulfates and/or nitrates to form ammonium sulfate and ammonium nitrate in the atmosphere. These ammonium compounds are classified as particulate emissions. The MOBILE6.2 model calculates and reports only the gaseous emissions emitted directly from a vehicle tailpipe. It makes no attempt to model the atmospheric chemistry of ammonia conversion to other ammonium based compounds or estimate the direct emissions from ammonium compounds. These types of calculation are left to atmospheric chemistry models.

3.4 Indirect Sulfate Emission Calculations

In addition to the direct sulfate emission factors discussed above, the previous model

(PART5) estimated an indirect sulfate emission factor by assuming that a fraction of the gaseous sulfur dioxide emissions are later converted in the atmosphere to sulfate material. Based on ambient sulfur and sulfate measurements in 11 cities, EPA estimated that 12 percent of all gaseous sulfur is converted to sulfate.

During the update process for MOBILE6.2 it was decided to drop this calculation from the model and not report an estimate for indirect sulfate emission production. The reasoning for this decision is that the MOBILE6.X series of models are vehicle emission models not atmospheric models. They are best used for estimating emission factors for pollutants directly emitted from vehicles through pathways such as exhaust, evaporation, brake and tire, and engine draft (PCV), rather than atmospheric chemical reactions.

3.5 Fugitive Dust Emission Calculations

MOBILE6.2 does not include estimates of fugitive road dust emissions. These will be covered by a simple calculation tool being developed separately by EPA's Office of Air Quality Planning and Standards (OAQPS). They were removed from the MOBILE6.2 because a new tool will be available, and because MOBILE6 cannot properly account for the facility / roadway type - unpaved roads. Since dust emissions on an unpaved road are usually considerably higher than on a paved road, the issue of paved versus unpaved roads is critical in any modeling or discussion of fugitive dust emissions.

The AP-42 methodology for calculating fugitive road dust does not permit attributing the emissions to particular vehicle classes in cases where multiple vehicle classes use the road. This also significantly complicates integrating the road dust calculation into MOBILE6. An EPA web site where the current AP-42 methods for calculation fugitive dust are explained is:

http://www.epa.gov/ttn/chief/index.html

The reader is encouraged to browse this web site for the necessary information on fugitive dust.

4. Results from the MOBILE6.2 Model

Some limited and preliminary results from the MOBILE6.2 model are shown at the end of this document, and are discussed in this section. (The notation in the Charts lists the term MOBILE6.1 at the top of the charts. The term MOBILE6.1 is completely synonymous with the name MOBILE6.2.)

4.1 Emissions Versus Calendar Year

These results are shown in a series of Figures (Figures 1 through 15). With the exception of the Ammonia results, all the figures were constructed as comparisons of the MOBILE6.2 and PART5 emission results. They are shown in terms of total particulate emissions (TOTEX), total carbon emissions from gasoline vehicles (GASPM), sulfate emissions and lead emissions. All of the results in these figures are shown as a function of calendar year. The results are also shown for individual vehicles types: light-duty gasoline vehicles, light-duty truck class 4 vehicles, heavy-duty gasoline vehicles, light-heavy, medium-heavy, and heavy-heavy duty diesel vehicles and transit diesel buses. The emission results in all of the figures are the average emission levels for each calendar year from 1970 through 2020. A calendar year includes the weighted average emission result of the current calendar year plus the previous 24 model years. All of the results are shown in terms of PM10 emissions (i.e., particles less than 10 microns in diameter). Results shown in terms of PM2.5 emissions would also be consistent between the MOBILE6.2 model and the PART5 model since particulate size determination algorithms did not change between the two models.

Figures 1 through 4 show the results from the light-duty gasoline vehicles. Figure 1 shows the TOTEX (total exhaust particulate emission) results from both MOBILE6.2 and PART5. As can be seen from the figure, only relatively small differences between the two models are observed. The differences occur mostly in the pre-1980 years and in the post 1996 calendar years. In the early years they are caused by differences in the underlying methodology of modeling misfueling and tampering effects on lead particulate emissions. The differences are not due to changes in the basic lead emission factors. The differences in the later years are due to different fuel sulfur levels that create differences in sulfate emission factors. The PART5 model does not allow alternate gasoline fuel sulfur levels to be modeled, and fixes this fuel parameter at 343 ppm. However, the MOBILE6.2 model allows alternative sulfur levels to be modeled. The fuel sulfur level was set at 30 ppm for all 2000 and later calendar years. Figure 2 shows the carbon particulate emissions comparison for light-duty gasoline vehicles without the contribution of lead and sulfate emissions. As can be seen in Figure 2, once the different lead and sulfur influences are removed, the carbon particulate emissions (GASPM) are shown to be very similar between MOBILE6.2 and PART5. Any differences between the two models is due to different fleet assumptions such as technology distributions or mileage accumulations.

Figure 3 illustrates the impact of different fuel sulfur levels on the sulfate emission factors. In the later calendar years, the higher PART5 sulfate curve shows the effect of a high fuel sulfur level

(343 ppm), and the lower MOBILE6.2 sulfate curve reflects a reduced sulfur level of 30 ppm after 1999. The rising and/or relatively high sulfate emission levels from the early 1980's until the 1990's depicted in both models is the result of increasing penetration of air injection systems on vehicles. Vehicles with air injection systems typically produce more sulfate and less gaseous SO2 than those without such systems. The very low sulfate emission factors after 2004 show the effect of very low fuel sulfur and the virtual elimination of air injection systems that lead to higher sulfate emission factors.

Figure 4 compares the lead emission factors between MOBILE6.2 and PART5. The figure shows that some differences occur in the pre-1980 model years due to a slightly different methodology of accounting for tampering and misfueling, and the different technology fractions in MOBILE6.2 and PART5. Both models show zero lead emissions after 1991 due to the complete phase-out of lead in gasoline.

Figures 5 and 6 show the average carbon PM10 emission results for light-duty gas truck class 4 and heavy-duty gas trucks for the MOBILE6.2 and PART5 models. As for the light-duty vehicles (i.e. cars), the results for MOBILE6.2 and PART5 for the trucks are relatively close for most calendar years. The differences for the light-duty gas trucks can explained in terms of truck size and different fleet and technology distributions between the two models. For instance, the figure shows the results for a light-duty gas truck class 4 in MOBILE6.2, but an average result for light-duty gas truck class 3 and 4 for PART5 (PART5 did not separate class 3 and 4 trucks). Also, sulfate and lead emission differences between the two models are also present in an analogous fashion as the light-duty gasoline vehicle graphs on “carbon PM”.

The heavy-duty gas truck result comparison in Figure 6 shows differences that are mostly technology related (different fleet phase-ins for fuel injected, air injection and catalyst technology) for emissions in the 1990 through 2005 calendar years. After calendar year 2008, the lower PM emission factors from MOBILE6.2 are the effect of the EPA Tier2 emission standards. These new standards are modeled in MOBILE6.2, but not in PART5.

Figures 7 through 10 show the TOTEX comparisons for the diesel vehicles. Comparison of the results in Figure 7 for Class 2B diesels shows MOBILE6.2 to be slightly higher for calendar years prior to 2007 and considerably lower for calendar years after 2007. For medium heavy-duty diesels shown in Figure 8, the relationship is just the opposite for the pre-2007 vehicles, but is similar for the 2007 and later trucks. For heavy-heavy duty vehicles shown in Figure 9 there are only slight differences for the pre-2007 calendar years, but similar lower emission factors for calendar years following 2007. The results for the Buses show the largest differences with MOBILE6.2 predicting considerably higher PM emissions for all but the latest calendar years shown in Figure 10.

The differences in the pre-2007 calendar years arise primarily because the MOBILE6.2 results reflect a more recent analysis done to support the EPA heavy-duty diesel 2007 rule whereas PART5 reflects an older analysis. The new analysis had an eight percent compliance margin to the standards overall, and in a few vehicle class cases (medium heavy-duty vehicles), some very small amounts of deterioration versus mileage. However, in most cases the direct regulated PM emission factors in units of grams per brake horsepower-hour (g/bhp-hr) did not change much. Instead, the conversion factors changed. This was particularly true in the case of the buses. Also, in the case of the buses the comparison is more difficult due to the change in category definition. In PART5, the buses category included all buses, in MOBILE6.2 they are broken out between urban transit buses and school buses.

All of the Figures 7 through 10 show considerably lower PM emissions for 2007 and later vehicles with MOBILE6.2 being much lower than PART5. This is due to the implementation of the new stringent 2007 diesel rule. In general, this rule will lower PM emissions by an order of magnitude from 0.1 g/bhp-hr to 0.01 g/bhp-hr. The effects of this rule were not accounted for in the PART5 model.

Figure 11 compares the MOBILE6.2 and PART5 model results for sulfate emissions on heavy-heavy duty diesel trucks. The PART5 curves are the default emission results that cannot be modified by the user. They typically are based on very high diesel fuel sulfur levels of 2500 ppm, and then a lower level of 500 ppm sulfur for all 1993 and later model years. The MOBILE6.2 results are based on 500 ppm sulfur for pre-2007 calendar years and 8 ppm diesel fuel sulfur for 2007 and later calendar years. Note that the MOBILE6.2 and PART5 sulfate curves agree when the fuel sulfur levels are the same at 500 ppm. If all the calendar-year MOBILE6.2 runs had been done at the same fuel sulfur levels as the PART5 runs, the curves would agree for all calendar years. Instead, alternate fuel sulfur levels were modeled (10 ppm fuel sulfur for 2007 and later) to show the effect of different diesel fuel sulfur levels on sulfate emissions.

Figure 12 shows the Ammonia emission factors as a function of calendar year and vehicle class. As can be observed, the diesel emission factors are not a function of calendar year, but the gasoline vehicle factors are a function of calendar year. The gasoline vehicles show a rising and then a flattening curve of ammonia as calendar year progresses. This rising curve is due to the fact that modern fuel injection and 3-way catalyst technology has a greater tendency to produce ammonia than the older non catalyst or oxygenated only catalyst equipped vehicles. The flattening aspect of the curve reflects the almost complete penetration of fuel injected and 3-way catalyst vehicles into the fleet by calendar year 2010.

Figure 13 compares the MOBILE6.2 and PART5 exhaust carbon particulate emissions for motorcycles. The figure shows close agreement between MOBILE6.2 and PART5. In both figures the emissions start out at fairly high levels in the 1970s and drop to considerably lower levels in the 1990 and beyond due to technology improvements.

Figure 14 compares the MOBILE6.2 and PART5 exhaust carbon emissions for light-duty diesel vehicles. The figure shows fairly good agreement between the models with similar overall trends. The models diverge after 2007 because of the incorporation of the effects of 2007 diesel rule on the MOBILE6.2 emission factors and the lack of such an effect in PART5. The PART5 graph shows an unusual ‘dip and increase’ in emission factors in the 1980 to 1989 calendar years. This effect is not due to rising general emission factors in the model, but changing registration distributions between individual model years. For example, in the calendar years where the emission rate is increasing the overall LDDV fleet is getting older (new model years are replacing older vehicles at a slower rate).

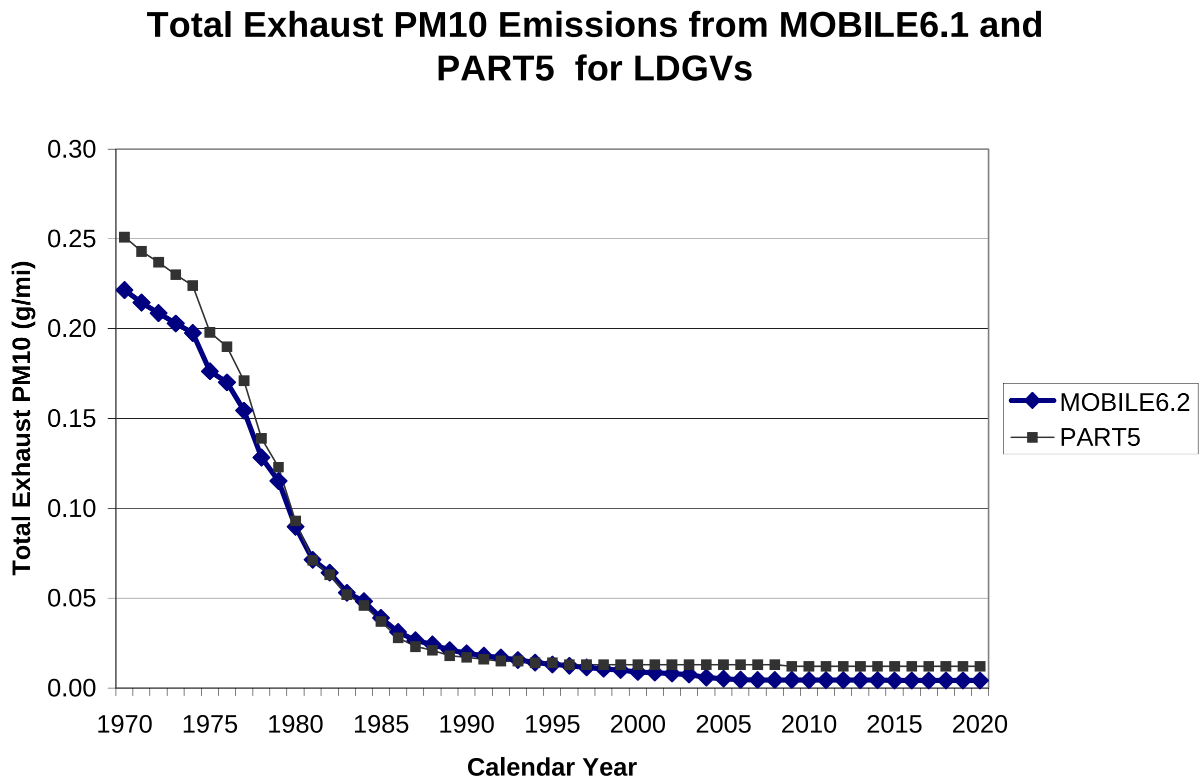
Figure 15 compares the MOBILE6.2 and PART5 exhaust carbon particulate emissions for light-duty diesel trucks. This figure is analogous to Figure 14 for the LDDVs. It also shows fairly good agreement between the models with similar overall trends. The models diverge after 2007 because of the effects of 2007 diesel rule on the MOBILE6.2 emission factors and the lack of such effect in PART5.

4.2 Emissions Versus Model Year

Figure 16 (the only figure based on model year instead of calendar year) presents Total Exhaust particulate emissions versus model year for the 8B heavy-duty diesel vehicles in calendar year 2010. These results show the basic emission factor for 8B diesel vehicles for each individual model year prior to the application of weighting factors and correction factors. In comparison, the results shown in Section 4.1 are by calendar year where each calendar year is a weighted average of the emission factors from the previous 25 model years.

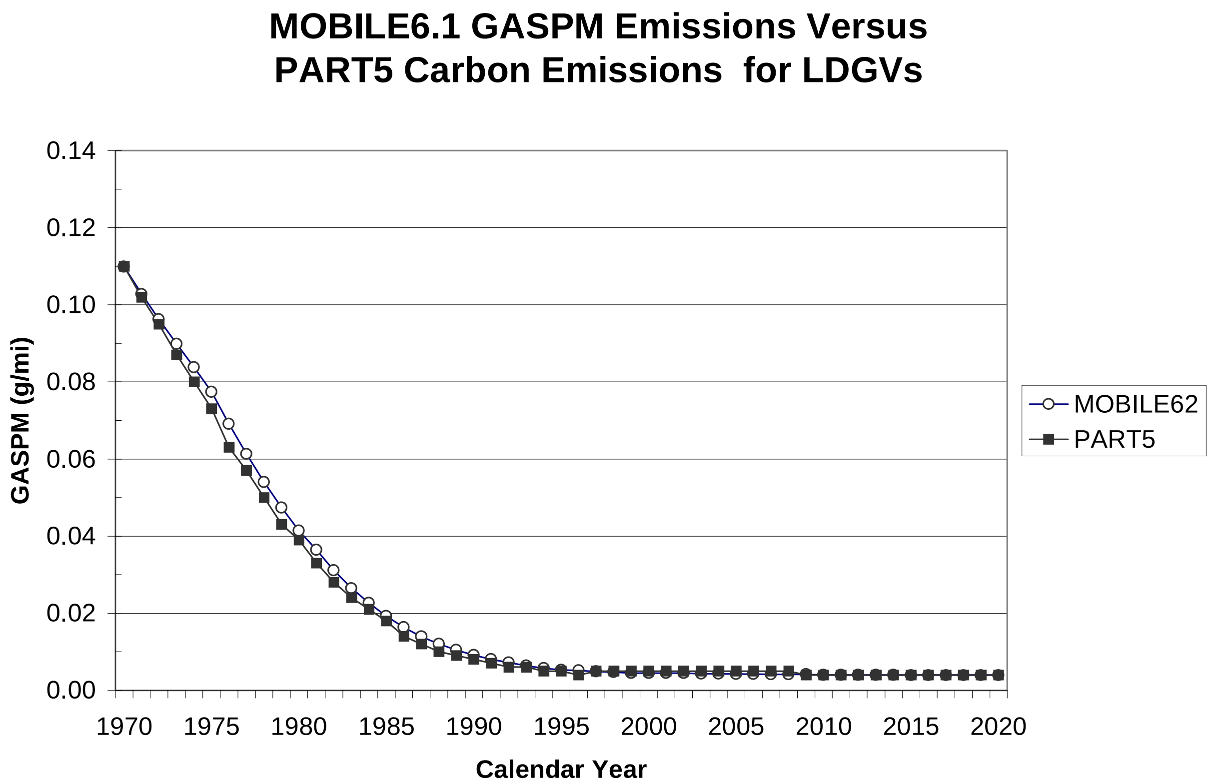
The results in Figure 16 show that the 8B and other heavy-duty diesel vehicle basic emission factors are NOT precisely the same as those from PART5. The differences in Figure 16 occur because different emission factors were used to model heavy-duty diesel vehicles in the EPA 2007 Heavy-Duty Rule-making effort than in PART5. The differences are most notable in model years 1984 through 1989 where the new MOBILE6.2 emission factors now include the effects of deterioration of particulate emissions versus vehicle odometer. Also, the MOBILE6.2 particulate emission factors for the 2007 and later model years are lower than the corresponding PART5 emission factors due to the effects of the 2007 rule-making.

Figure 1



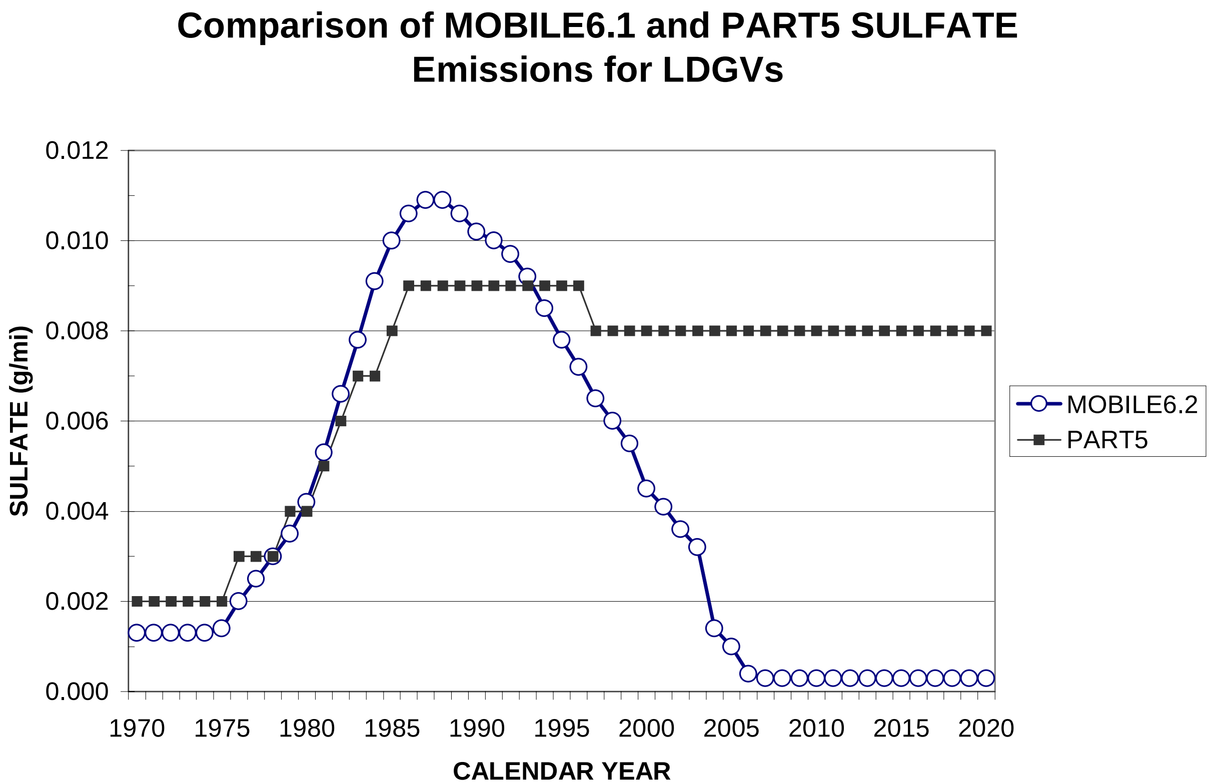
Total Exhaust PM10 Emissions from MOBILE6.1 and PART5 for LDGVs
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Total Exhaust PM10 (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

Figure 2



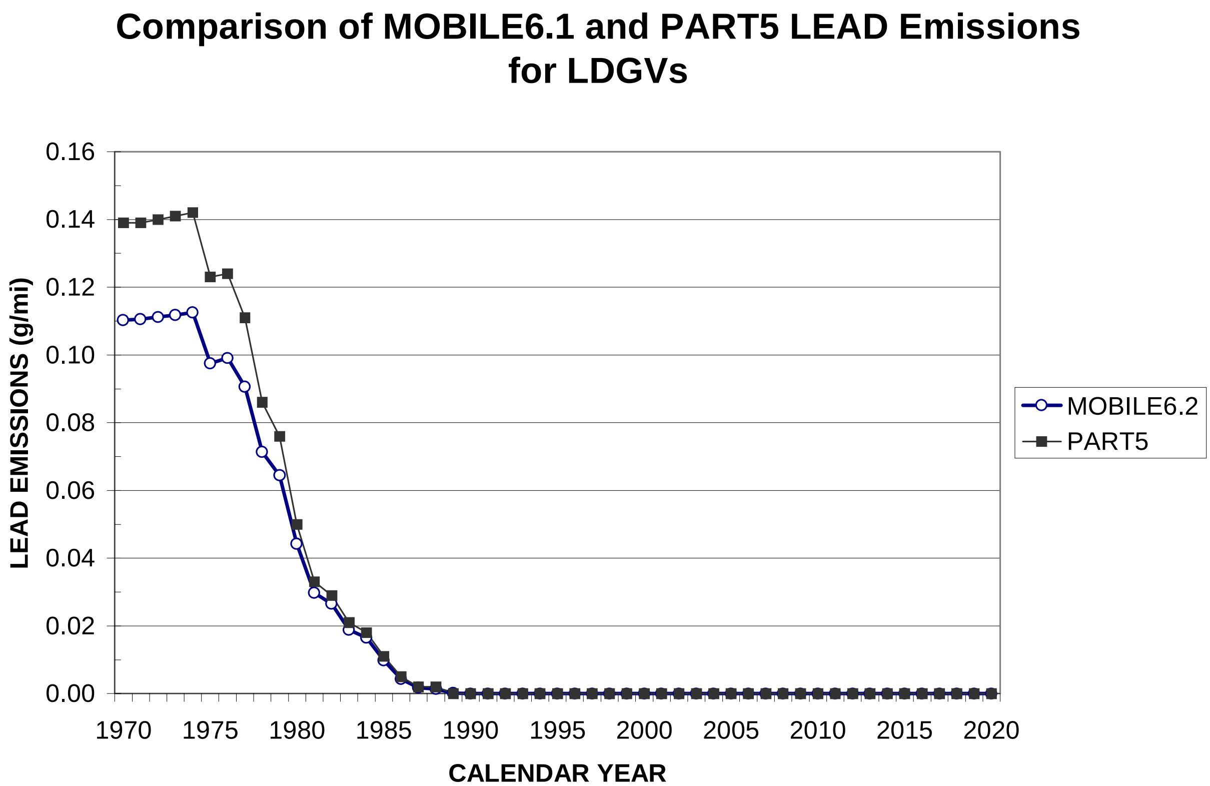
MOBILE6.1 GASPM Emissions Versus
PART5 Carbon Emissions for LDGVs
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
GASPM (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE62
PART5

Figure 3



Comparison of MOBILE6.1 and PART5 SULFATE Emissions for LDGVs
SULFATE (g/mi)
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

Figure 4



Comparison of MOBILE6.1 and PART5 LEAD Emissions
for LDGVs
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
LEAD EMISSIONS (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

Figure 5

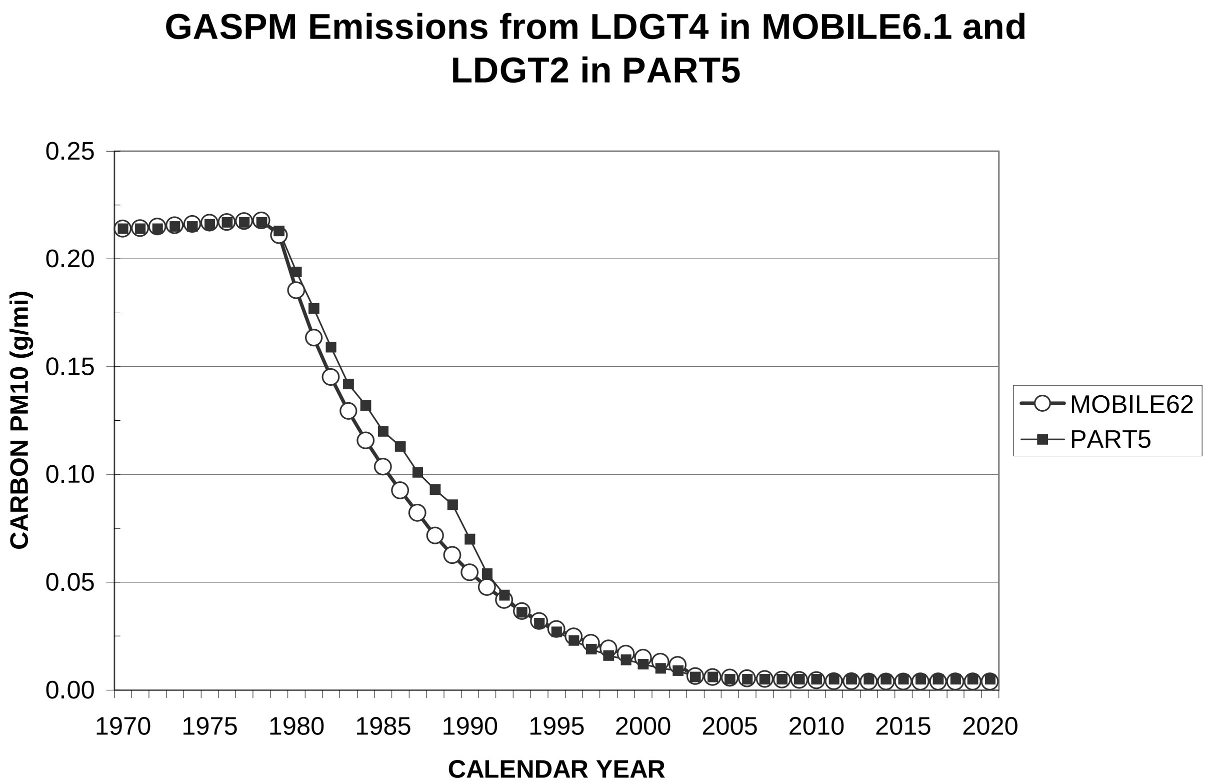

GASPM Emissions from LDGT4 in MOBILE6.1 and LDGT2 in PART5
0.25
0.20
0.15
0.10
0.05
0.00
CARBON PM10 (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE62
PART5

Figure 6

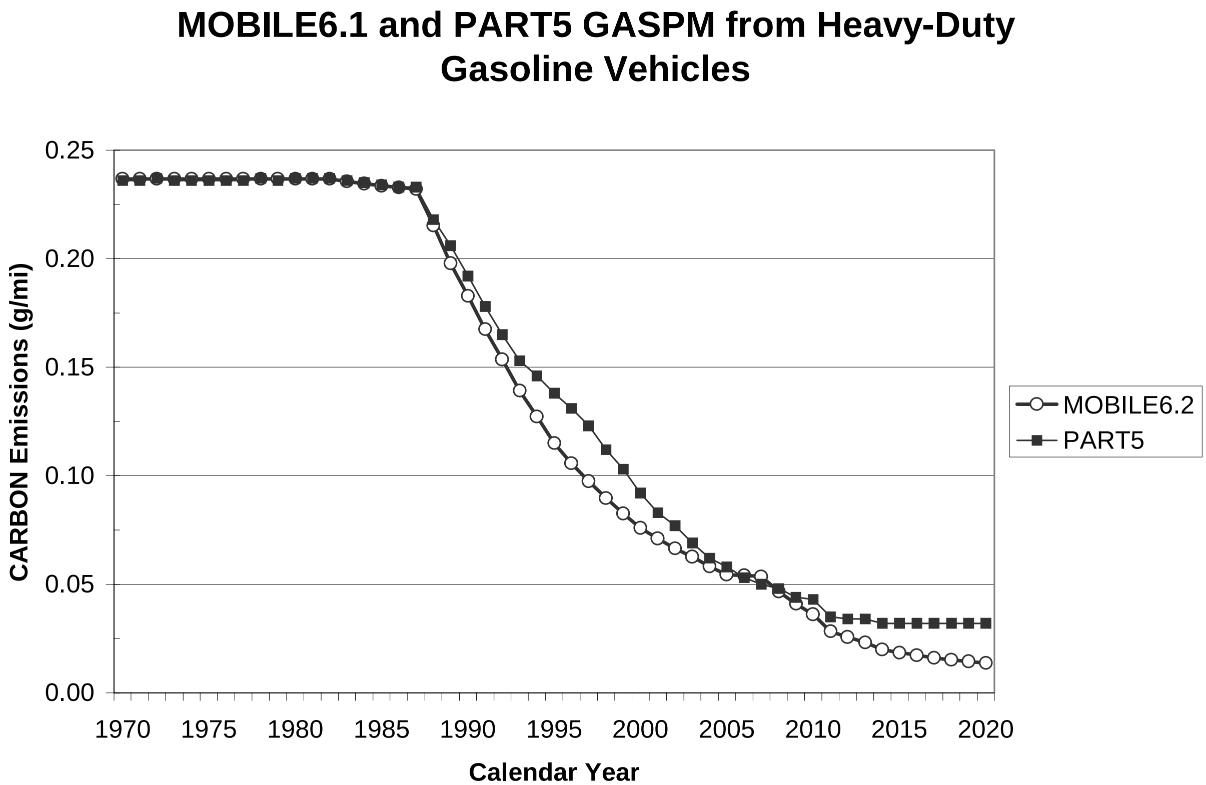
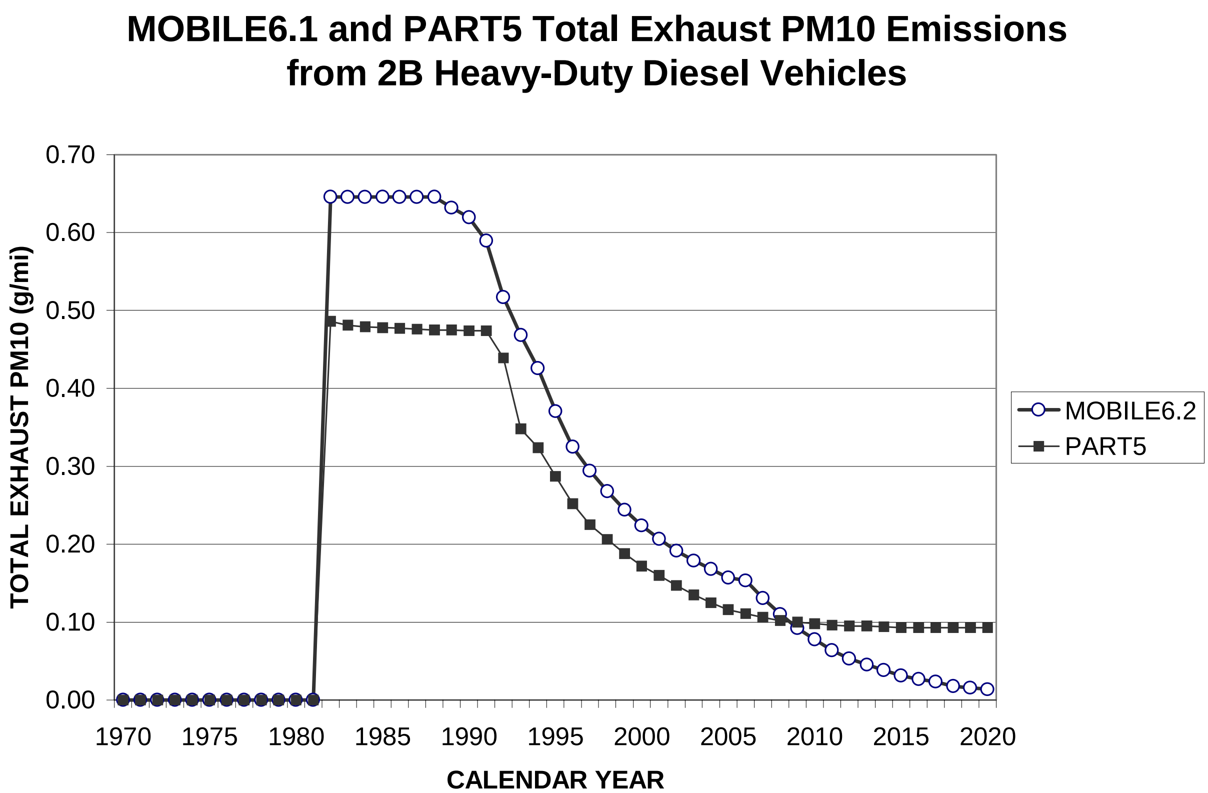

MOBILE6.1 and PART5 GASPM from Heavy-Duty Gasoline Vehicles
0.25
0.20
0.15
0.10
0.05
0.00
CARBON Emissions (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

Figure 7



MOBILE6.1 and PART5 Total Exhaust PM10 Emissions
from 2B Heavy-Duty Diesel Vehicles
TOTAL EXHAUST PM10 (g/mi)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

Figure 8

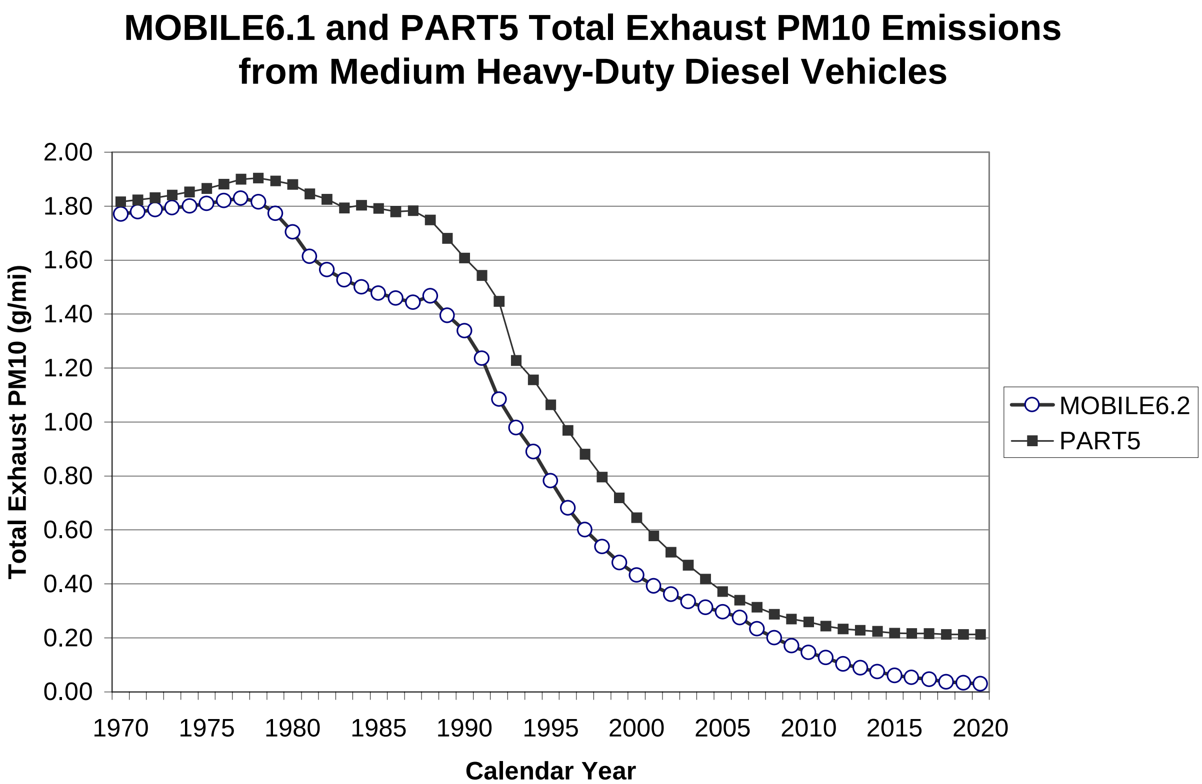

MOBILE6.1 and PART5 Total Exhaust PM10 Emissions
from Medium Heavy-Duty Diesel Vehicles
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Total Exhaust PM10 (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

Figure 9

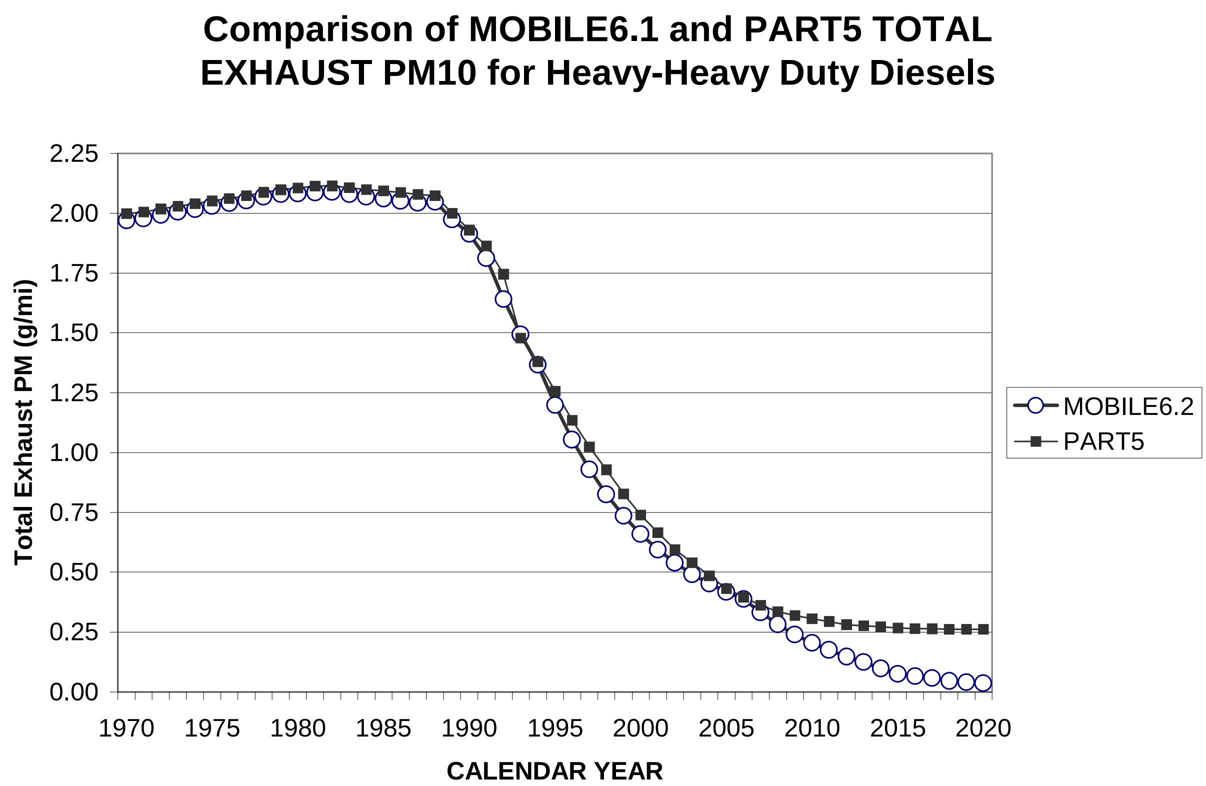

Comparison of MOBILE6.1 and PART5 TOTAL EXHAUST PM10 for Heavy-Heavy Duty Diesels
Total Exhaust PM (g/mi)
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

Figure 10

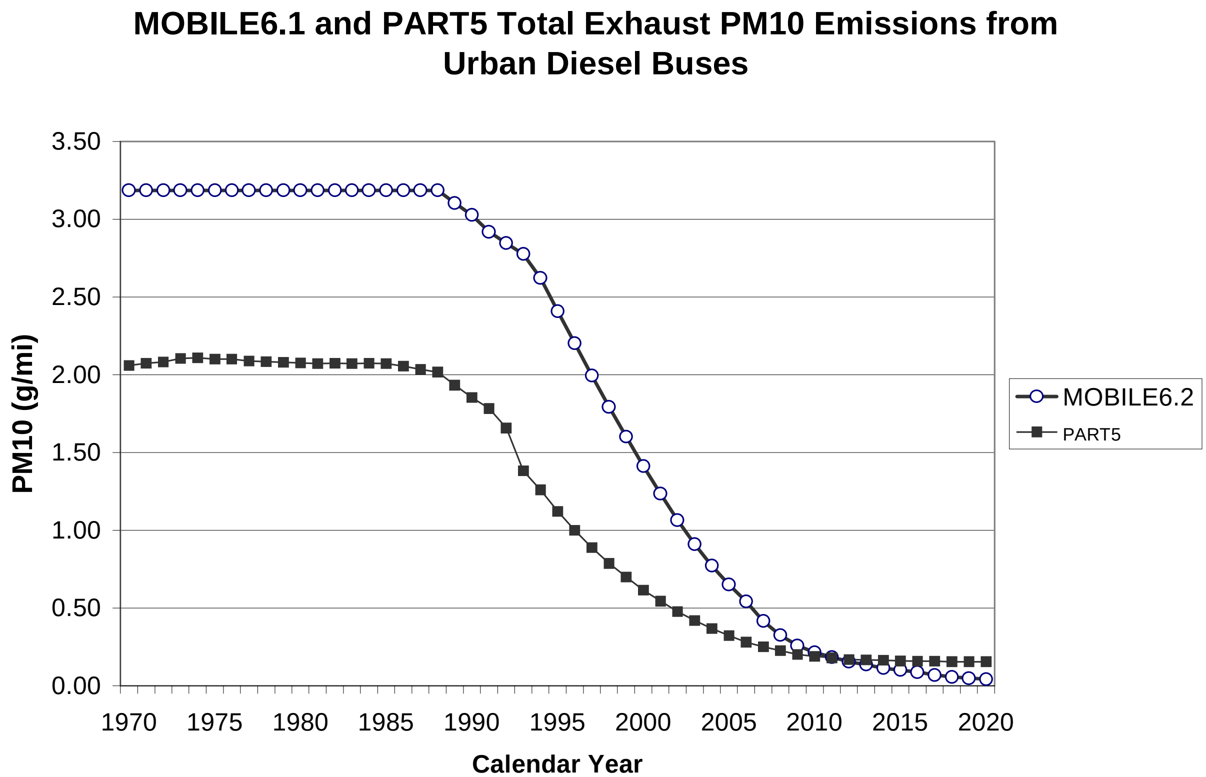
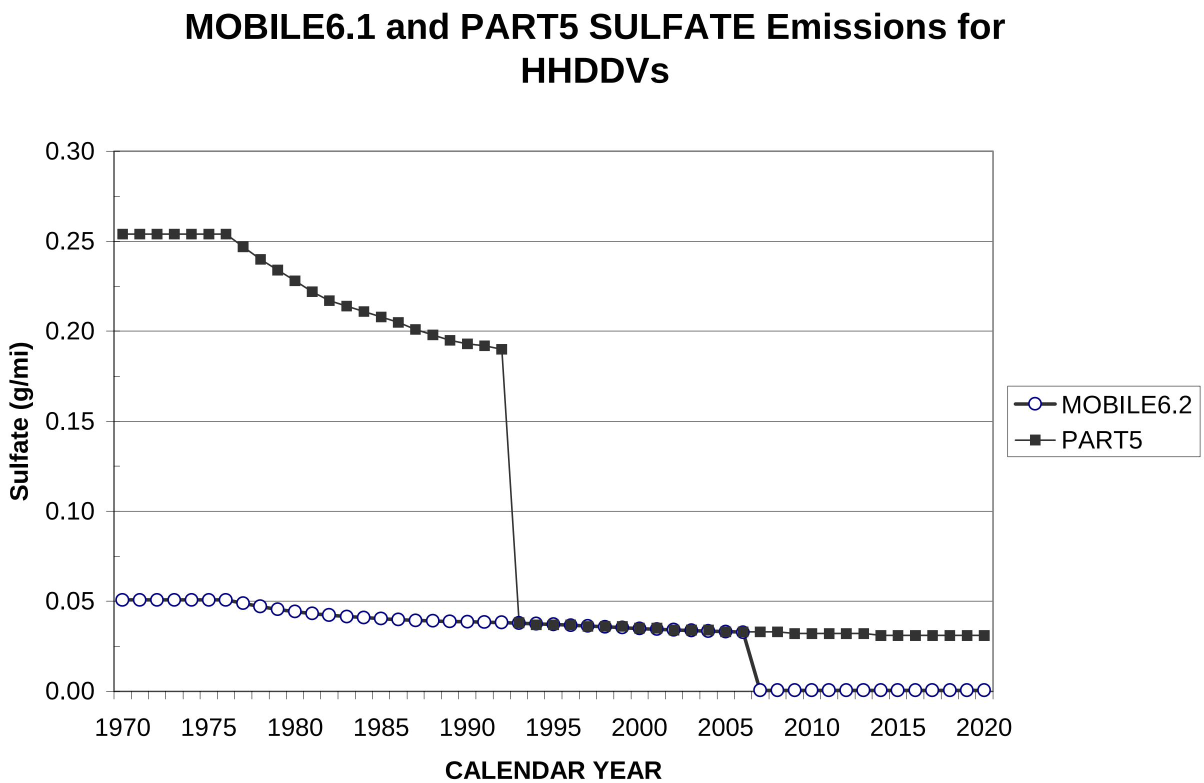

MOBILE6.1 and PART5 Total Exhaust PM10 Emissions from Urban Diesel Buses
PM10 (g/mi)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

Figure 11



MOBILE6.1 and PART5 SULFATE Emissions for HHDDVs
Sulfate (g/mi)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

Figure 12

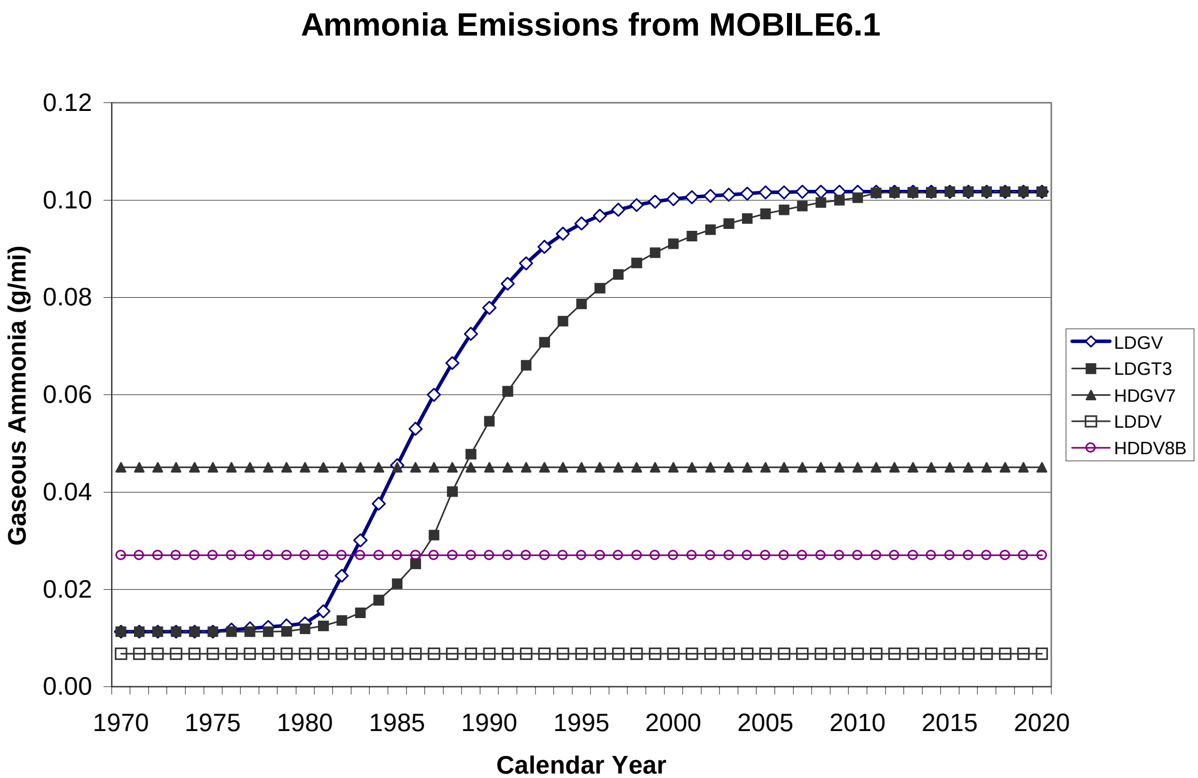
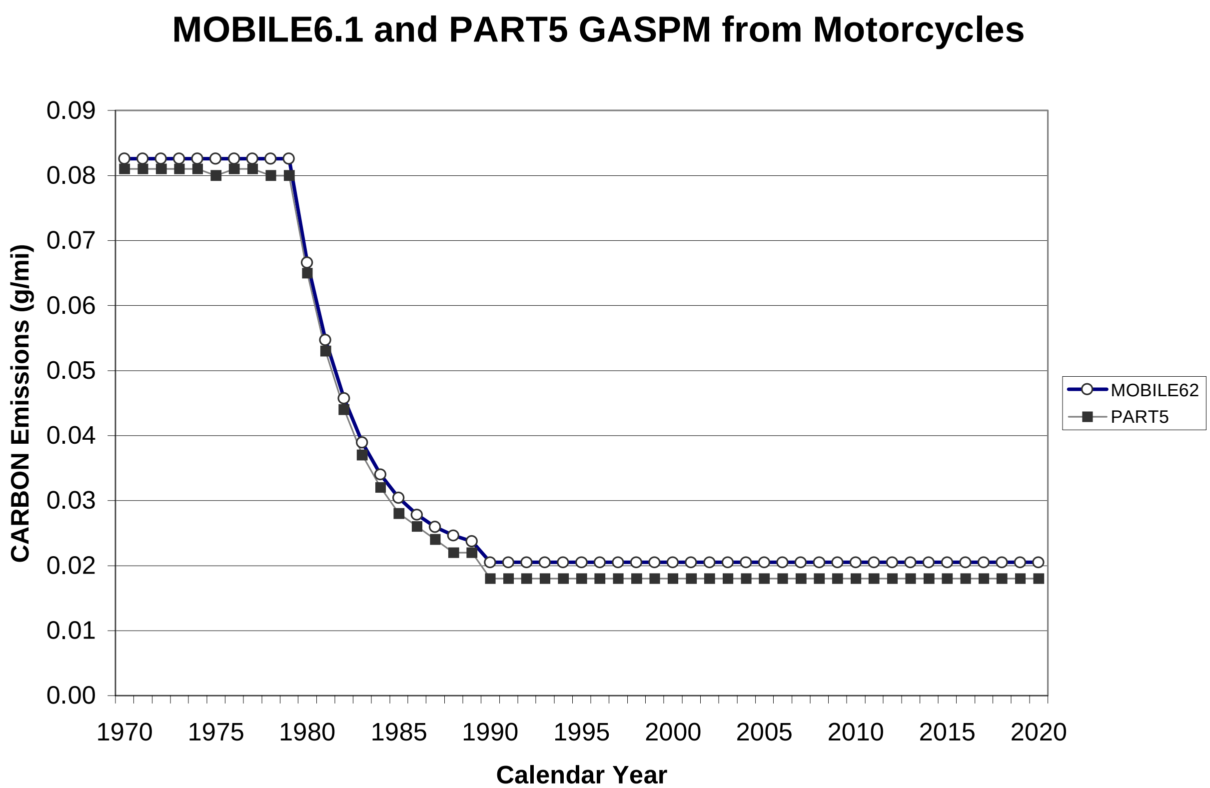

Ammonia Emissions from MOBILE6.1
Gaseous Ammonia (g/mi)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
LDGV
LDGT3
HDGV7
LDDV
HDDV8B

Figure 13



MOBILE6.1 and PART5 GASPM from Motorcycles
CARBON Emissions (g/mi)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE62
PART5

Figure 14

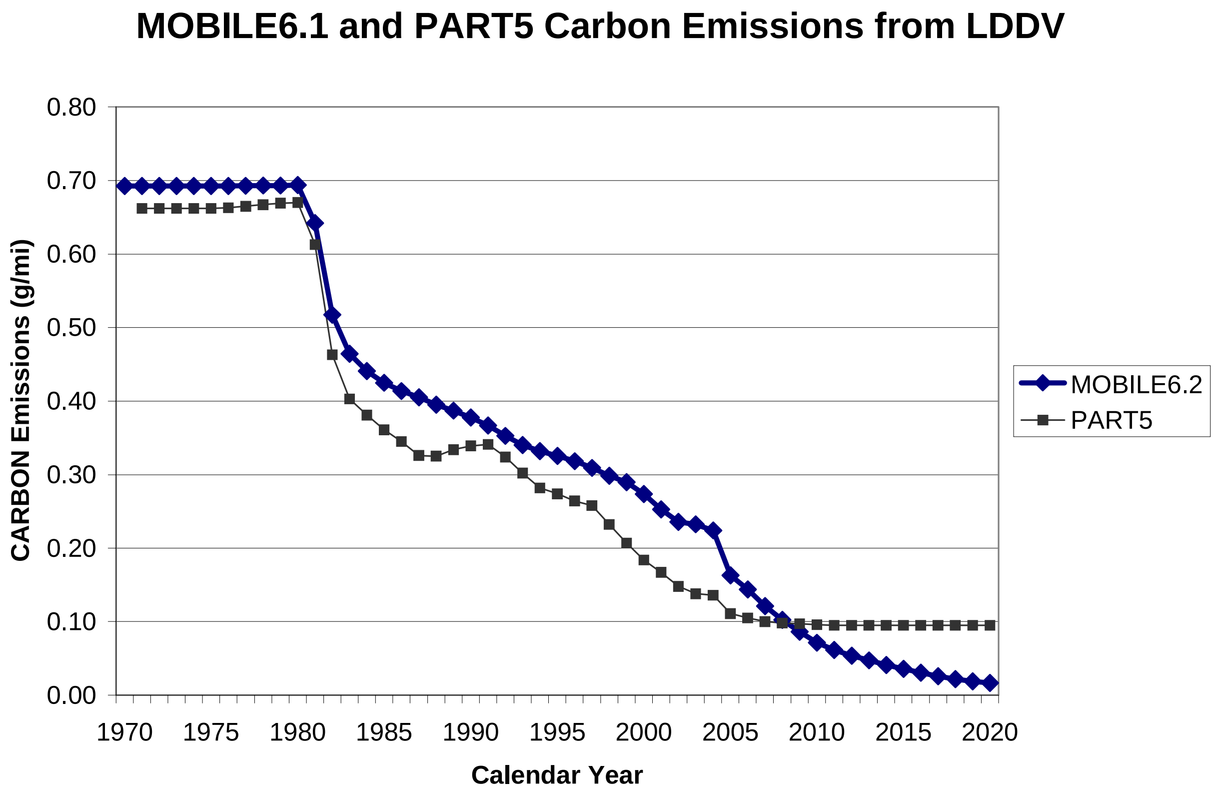

MOBILE6.1 and PART5 Carbon Emissions from LDDV
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
CARBON Emissions (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

Figure 15

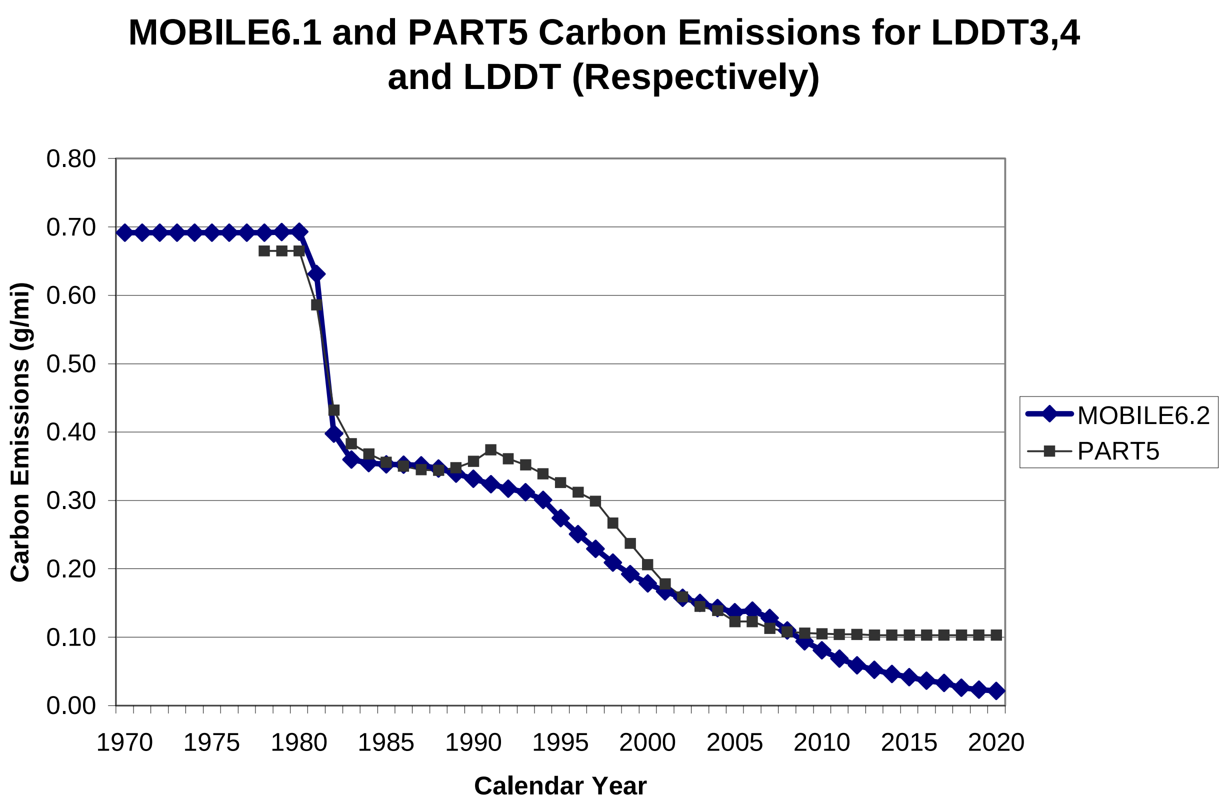
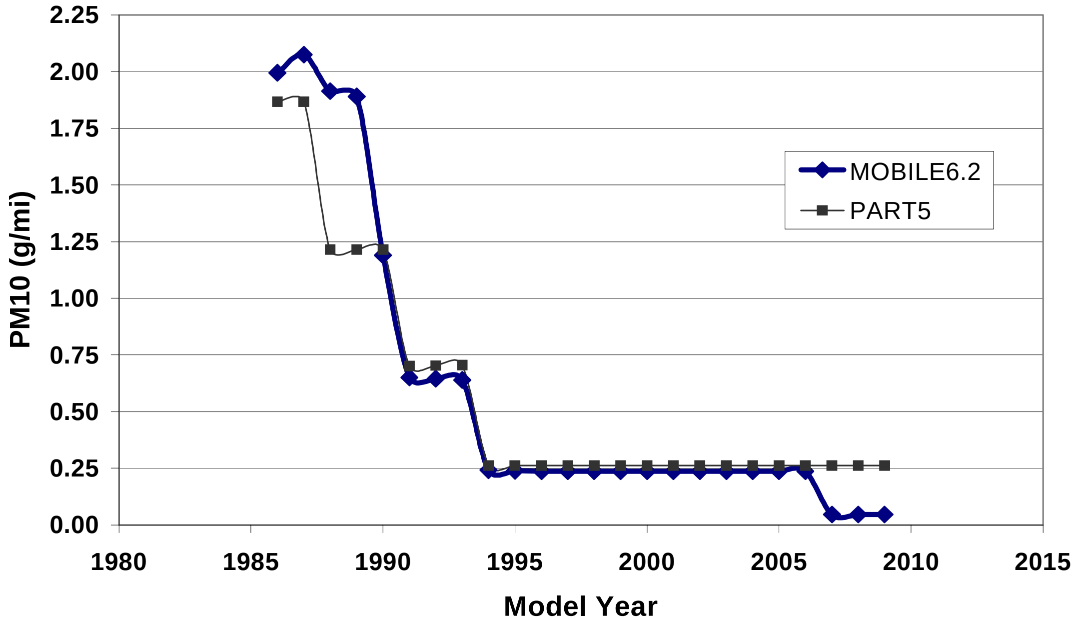


Figure 16

PM10 Emission Factors for 8B Diesel Vehicles In Calendar Year 2010



Appendix A

Literature Search on Vehicle Ammonia Emissions

The ammonia emission factors used in the MOBILE6.2 model are based on a 1981 EPA study which tested only limited numbers of 3-way catalyst vehicles. Thus, as part of the MOBILE6.2 update, EPA did a literature search to determine if other ammonia emission estimates were available, and to determine if the MOBILE6.2 estimates based on this study were appropriate.

Recent studies on vehicle ammonia emissions by various researchers have suggested that gaseous exhaust ammonia emissions may be dependent on catalyst type, vehicle operation and fuel sulfur levels. The 1981 study does take different catalyst types into account (although, the 1981 3-way catalyst may not reflect modern technology). However, it did not address ammonia emissions as a function of vehicle operation or fuel sulfur levels. As a result, the ammonia emission factors in the MOBILE6.2 model may be only partially representative of modern vehicles.

Various Studies

1989 Volkswagon Study - Several gasoline and diesel vehicles were studied using the FTP test. The gasoline sulfur level was 330 ppm. Non-catalyst gasoline vehicles reported results of 3.52 mg/mi, diesel vehicles 1.88 mg/mi and 3-way catalyst vehicles 137.4 mg/mi.

Preliminary CE-CERT Work in Calendar Year 2000 - Seven vehicles tested so far over three different fuel sulfur levels (324 ppm and 30 ppm and California reformulated fuel). The vehicles were a 1991 Dodge, a 1997 Ford, a 2001 Buick, a 1999 Ford Tier1, a 2001 Suzuki NLEV, a 1999 GM Sonoma TLEV, a 2000 Ford Winstar ULEV. All were 3-way catalyst technology.

Table A-1
CE-CERT Vehicle Test Results of Ammonia Emissions

	FTP		US06	
Vehicle	30 ppm Sulfur	324 ppm Sulfur	30 ppm Sulfur	324 ppm Sulfur
1991 Dodge	118 mg/mi	86 mg/mi	210 mg/mi	161 mg/mi
1997 Ford	38 mg/mi	5 mg/mi	237 mg/mi	146 mg/mi
2001 Buick*			160 mg/mi	
1999 Ford*	70 mg/mi		242 mg/mi	
2001 Suzuki*			415 mg/mi	
1999 GM*	12 mg/mi		82 mg/mi	
2000 Ford*	73 mg/mi		307 mg/mi	

```
* Tested on California Reformulated Fuel rather than the fuels
with the specified sulfur levels of 30 and 324 ppm.
```

ORD National Risk Management Research Laboratory Work - One 1993 Chevrolet Lumina (3-way catalyst) was tested over various driving conditions (FTP, steady state, hard acceleration, partial and major enrichment, and some on road data). The FTP ammonia emissions were about 30 mg/mi. This is lower than other studies. However, the hard acceleration results were 282 mg/mi, and the major enrichment results were 2,450 mg/mi.

G. Cass Work - California Institute of Technology - These were roadway tunnel studies in Los Angeles in 1998. The results were 98 mg/mi ammonia for the fleet as a whole. 116 mg/mi for LDGV.

A. Kean Work - Lawrence Berkeley Labs - A San Francisco Bay area tunnel study in 1999. Results 79 mg/mi overall fleet result.

M. Baum Work - Oak Crest Institute of Science, CA. - They used remote sensing measurements. Emissions were measured from vehicles during acceleration in parking lots and freeway ramps. Results showed very high emissions. The results are available only in ppm (78.6 ppm average). 66% of the ammonia emissions are emitted by 10% of the fleet. M-85 fueled vehicles had slightly higher ammonia emissions.

Future Work - EPA Office of Research and Development studies, CE-CERT under EPA cooperative agreement, and CRC testing project. Future focus will be on determining fuel effects, and how ammonia emissions change as NOx emissions are controlled.

Appendix B

Response to Comments

Appendix B is a response to specific technical comments submitted by the Engine Manufacturer's Association (EMA) on this current document. For convenience, the comments and the corresponding responses (shown in italics) are provided here as an appendix.

1. EMA questions the accuracy of the estimate of PM emissions by component for a 2007 and later Class 8b vehicle operating on 15 ppm diesel sulfur fuel. More specifically, the model's estimates of elemental carbon emissions of 20.8 mg/mile and organic carbon emissions of 6.6 mg/mile are erroneously high. In fact, for filter-equipped diesel engines, which all 2007 and later engines will be, the elemental carbon and organic carbon portions of the total PM essentially are zero. The only PM exhaust emissions will be from sulfates, which are a result of the sulfur in the diesel fuel. Indeed, EPA's own analysis with respect to 2007 and later PM standards bears this out. EPA estimated that total PM emissions for the 2007 and later model years would be 0.005 g/hp-hr, based on EPA's assumptions of 7 ppm sulfur diesel fuel and 70% conversion of the sulfur mass to sulfate. In other words, all the exhaust PM is sulfate and, hence, none is elemental carbon or organic carbon. The model should be revised to reflect the absence of carbon emissions from 2007 and later engines.

Response to #1

While the prospect of essentially zero emissions from diesel trucks is extremely encouraging from an environmental perspective, the limited and preliminary emission test data referenced in the above comment is undoubtably from engine and vehicle sources which should be considered as engineering prototypes. As such, these prototypes have most likely not received the necessary field testing in significant quantities and under a wide variety of adverse conditions such that we can assume that this performance is realistic of fleet-wide operation in the future. If such data appear in the next upgrade cycle of this model (MOVES emission model)*, EPA will be pleased to include it. In the meantime, the assumption that the 2007 and later model year heavy-duty diesel vehicles will meet and exceed the 2007 rule requirements with an 8 percent compliance margin over their entire lifetimes seems sufficiently aggressive at this stage.*

2. Diesel fuel sulfur level is a required input to the model to estimate particulate. However, there is no guidance for states and others to use on what sulfur levels should be assumed for various years, as there is for gasoline sulfur levels. EPA should publish guidance in the Users Guide on recommended diesel sulfur levels for all calendar years. Otherwise, users may enter the incorrect values, resulting in sulfate PM emissions and SO_2 emissions that are incorrect.

Response to #2

EPA recognizes that the burden is now placed on the user to supply the required fuel sulfur input. As such, EPA is working on a MOBILE6.2 Guidance document in which diesel fuel sulfur inputs will be discussed.

3. The diesel fuel sulfur level command does not differentiate between diesel fuel used in 2007 and later engines and diesel fuel used in pre-2007 engines. EPA's modeling for the 2007 and later diesel fuel sulfur rule shows that EPA assumed that for the 2007-2010 phase-in years, 100% of 2007 and later engines receive low sulfur fuel, but only about 80% of pre-2007 engines receive low sulfur fuel in the 2007-2009 time period. In order to accurately estimate sulfate and SO_2 emissions from the fleet, EPA should establish two different sulfur commands – one for 2007 and later engines, and one for pre-2007 engines – as in the diesel fuel sulfur rule.

Response to #3

EPA regrets to say that the diesel fuel sulfur command is not a function of vehicle model year, but only a function of calendar year. As such, the potential fuel program mentioned in the comment cannot be easily modeled with a single MOBILE6.2 run. Instead, separate runs of the model with different fuel sulfur levels will have to made with a weighting of the results outside of the model.

4. The documentation for the 2007 and later PM standards indicates that EPA assumed that 70% of the sulfur mass for 2007 and later engines is converted to sulfate. The MOBILE6.1 model, however, assumes only a 2% conversion of sulfur mass to sulfate, which is a carryover from the pre-2007 engines. The model should be changed to reflect the 70% estimate for 2007 and later engines.

Response to Comment #4

EPA is currently committed to a new test program that obtains additional data from current and potentially future vehicles and engines. If such data suggest a higher conversion of fuel sulfur to sulfate rather than to gaseous sulfur dioxide, EPA will update the emission factor model in the next cycle (MOVES emission factor model).

5. The MOBILE6.1 model uses particle size cutoffs to estimate the mass of PM at or below certain particle size cutoffs. The documentation for these particle size distributions, however, indicates that the distributions may have been based on fractions of total particles, rather than mass. This should be carefully reviewed by EPA. If the distributions are based on fraction of particles rather than mass, then these distributions cannot be used to estimate mass. If the documentation is incorrect, then the documentation should be changed to indicate that these are fractions of PM mass at or below each cutoff. It would also be helpful for EPA to reference the studies that were used to develop the particle size cutoffs, as no references were provided in either the MOBILE6.1 documentation or the earlier PART5 Users Guide. References also were not found in the EPA documentation for the organic carbon fractions; these should be supplied as well.

Response to Comment #5

As a result of the EMA comment, EPA identified that the labeling in both this technical document and the previous PART5 documentation was in error. The size distributions are in terms of mass and their use in the model is in terms of mass. The References Section of this document now contains the primary reference to the EPA particulate size distribution work. EPA wishes to thank EMA for pointing out this documentation error which had persisted for several years.

6. The PM emission rates for heavy-duty engines use conversion factors that are combined over various vehicle classes, resulting in the same PM emission rates in g/mi for different class trucks. For example, the PM emission rates for class 8a and 8b trucks are identical, although the conversion factors for these classes are not identical. EPA should revise the PM emissions for each class to utilize the class-specific conversion factors developed for MOBILE6.

Response to Comment #6

Unfortunately, the current data on particulate emission is insufficient to differentiate between these classes of heavy heavy-duty diesel in terms of particulate emission factors in units of grams per brake horsepower hour. When sufficient data becomes available we will be pleased to differentiate the emission performance of all classes of heavy-duty diesels, and update the emission factor model in the next cycle (MOVES emission factor model)

7. EPA added ammonia to the emission factors reported by MOBILE, based on work performed by EPA around 20 years ago. EMA questions whether it is appropriate to include ammonia emission rates for diesel vehicles, as EMA is not aware of any diesel exhaust ammonia emissions. Moreover, EPA has included no explanation as to why it is appropriate to include ammonia emission rates for diesel vehicles, and has included ammonia emission rates based on extremely old data. EMA strongly recommends that EPA eliminate ammonia emission rates for diesel vehicles based on the lack of data indicating the need for them in EPA's emissions inventory model.

Response to Comment #7

Unfortunately, ammonia emission data is relatively scarce on diesel vehicles. This necessitated the use of older and hopefully representative data. If new ammonia emission data becomes available from an upcoming test program, EPA will use it to update the diesel ammonia emission in the next emission factor model cycle (MOVES emission factor model).

Appendix C

References

EPA-AA-AQAB-94-2, "Draft User's Guide to PART5: A Program for Calculating Particle Emissions from Motor Vehicles", February, 1995.

EPA 460/3-85-005, "Size Specific Total Particulate Emission Factors for Mobile Sources", 1985.

Garbe, Robert, EPA/AA/CTAB/PA/81-20 "Determination of a Range of Concern for Mobile Source Emissions of Ammonia", August, 1981.

EPA 2007 Heavy-Duty Diesel Rule-Making Docket. See www.epa.gov/otaq/diesel.htm for more information.

EPA Tier 2 Gasoline Vehicle and Fuel Rule-Making Docket. See www.epa.gov/otaq/url-fr.htm and search for the Tier2 rulemakings.

EPA420-R-01-033, "Modeling Emission Factors for Compressed Natural Gas Vehicles", April, 2001.

Fugitive Dust Web Site and Reference for AP-42. See http://www.epa.gov/ttn/chief/index.html

Diesel and Gasoline Emission Factor Files; See Attachments PMDZML.csv, PMDDR1.csv, PMDDR2.csv, PMGZML.csv, PMGDR1.csv, and PMGDR2.csv. These files contain the basic PM emission factors used in the MOBILE6.2 model.