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# MOBILE6.1 Particulate Emission Factor Model Technical Description

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## 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 The PART5 model is now outdated.

The MOBILE6.0 model is the most recent EPA emission factor model. It calculates average 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.

The MOBILE and PART5 models 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 the PART5 and MOBILE6.0 models 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 basic particulate emission rates for future model years have been updated in MOBILE6.2 to reflect recent rulemakings.

## 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 project was to produce, in the relatively short term, a combined model that reflects EPA particulate emission modeling done for recent vehicle emission control rulemakings. The project takes into account the fuel sulfur level reductions that are now mandated, and new vehicle emission standards.

The project was also originally intended to take into account particulate test data that have become available since PART5 was produced, including in-use testing by EPA and other parties. EPA has concluded, however, that these data are insufficient to update the basic particulate emission rates at this time.

The foundation of MOBILE6.2 is, therefore, the basic mobile source particulate emission rates from the PART5 PM model and from EPA rulemaking modeling sources. These sources are supported by a large body of engine and vehicle certification test results.

An additional feature of MOBILE6.2 is that it allows the user to enter alternative basic exhaust particulate rates into the model as a function of vehicle class, model year, catalyst technology, and vehicle age. Also, deterioration estimates as a function of mileage can now be added. This will allow a sophisticated user to model a specific fleet and perform more complex modeling exercises if they can supply defensible particulate emission factors.

Section 3 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** **Base Emission Rates** - 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 Rulemaking 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 rulemaking requirements in 2004, and with the 2005 heavy-duty gasoline vehicle rulemaking, 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 subseqent 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 Eqn 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, 4$^{th}$ 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 rulemaking 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<br>Gasoline Vehicle Sulfate Emission Factors<br>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.

$$\text{Total Exh PM} = \text{OCARBON} + \text{ECARBON} + \text{Sulfate} \qquad \text{Eqn 3.10b}$$

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 PMDIES_ZML.xls, PMDIES_DET1.xls and PMDIES_DET2.xls. 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 rulemakings 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 the Table.

## Table 3.4
## Fraction of Particles 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 |

**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 PMGAS_ZML.xls, PMGAS_DET1.xls and PMGAS_DET2.xls.

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<br>MC is the motorcycle class<br>HDG are the heavy-duty gas vehicles<br>LDD are the light-duty diesel vehicles<br>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 <u>Indirect Sulfate Emission Calculations</u>

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 the new tool is 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.

# 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.

## 4.1 Emissions Versus Calendar Year

The results are shown in a series of Figures (Figures 1 through 15). 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 previous 25 model years.

With the exception of the Ammonia results, all the figures were constructed as comparisons of the MOBILE6.2 and PART5 emission results.

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 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 underlying methodology of modeling misfueling and tampering effects on lead particulate emission in between MOBILE6 and PART5. They 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 3 illustrates the impact of different fuel sulfur levels on the sulfate emission factors. Once the different lead and sulfur influences are removed, the carbon particulate emission (GASPM) is shown to be very similar between MOBILE6.2 and PART5 (see Figure 2).

Figures 5 and 6 show the average TOTEX 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).

The heavy-duty gas truck result comparison shows differences that are mostly technology related (different fleet phase-ins for fuel injected, air injection and catalyst technology) for emission in the 1990 through 2005 calendar years, and EPA Tier2 standards related effects for the 2008 and later calendar years.

Figures 7 through 10 show the TOTEX comparisons for the diesel vehicles. For heavy-heavy duty vehicles there are only slight differences, but for most vehicle classes there are some significant differences. The differences arise because the MOBILE6.2 model follows the analysis done to support the EPA heavy-duty diesel 2007 rule. In general, the MOBILE6.2 results are higher than those predicted by the PART5 model (this is particularly true for the transit buses - see Figure 10). An exception is the 2007 and later model years which reflect the implementation of the new stringent 2007 diesel rule. 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, and shown in Figure 11, to compare the effects of fuel sulfur between the two models, and to show the effect of different diesel fuel sulfur level 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. 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.

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 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 <u>Emissions Versus Model Year</u>

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 Rulemaking 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 rulemaking.

## 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

## References

EPA-AA-AQAB-94-2 “Draft User’s Guide to PART5: A Program for

Calculating Particle Emissions from Motor Vehicles", February, 1995.

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 Rulemaking Docket.

**Figure 1**

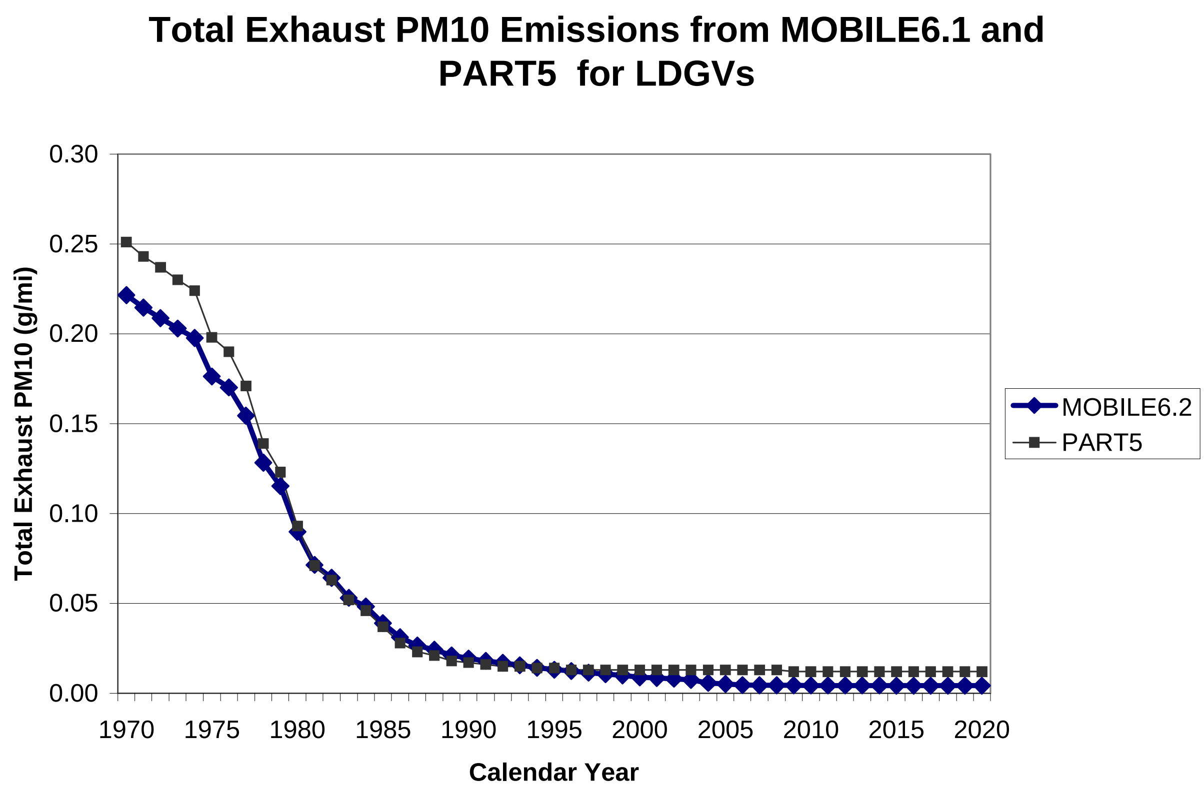

Total Exhaust PM10 Emissions from MOBILE6.1 and PART5 for LDGVs
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Total Exhaust PM10 (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

**Figure 2**

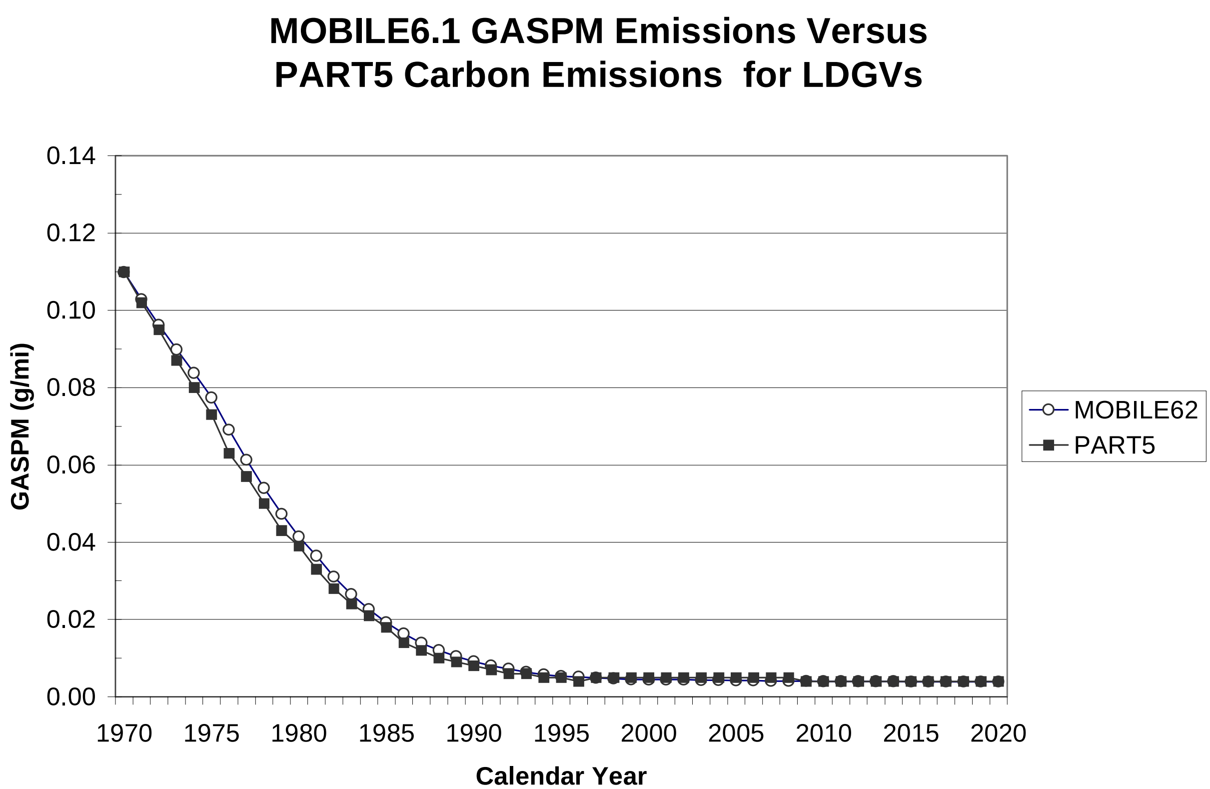
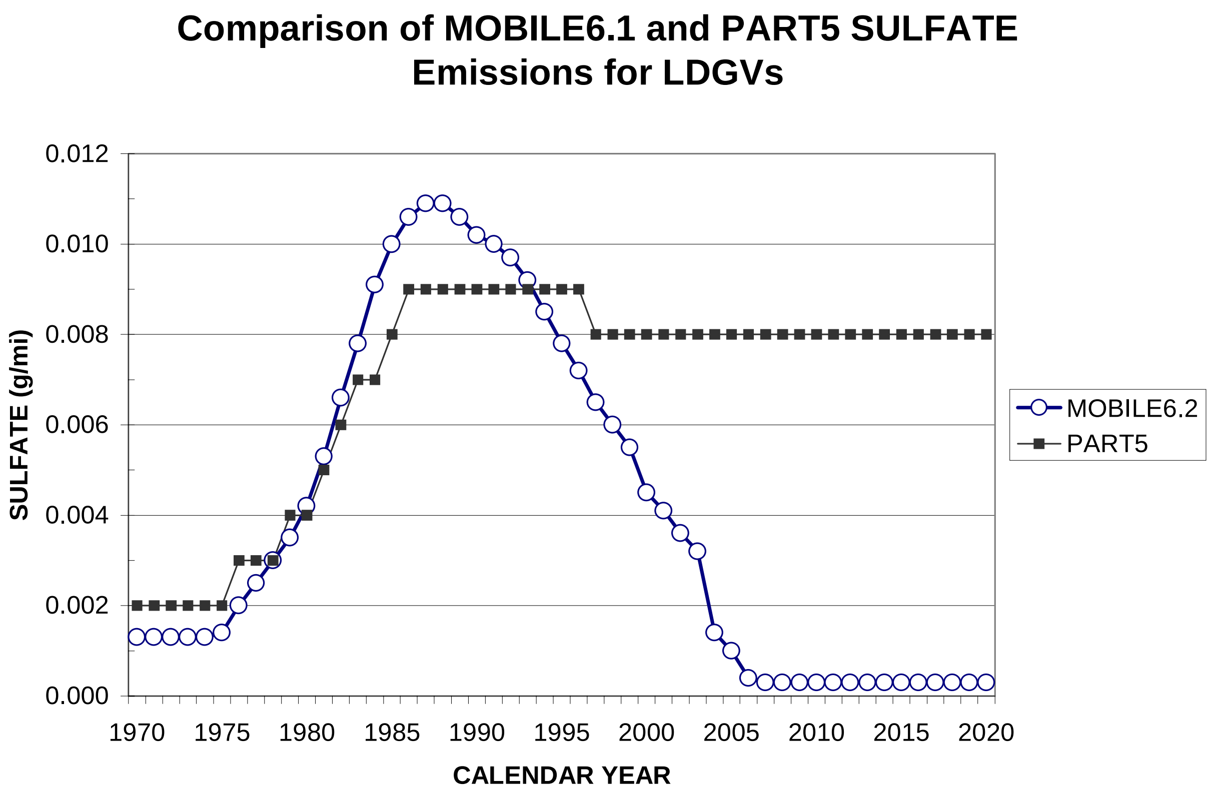
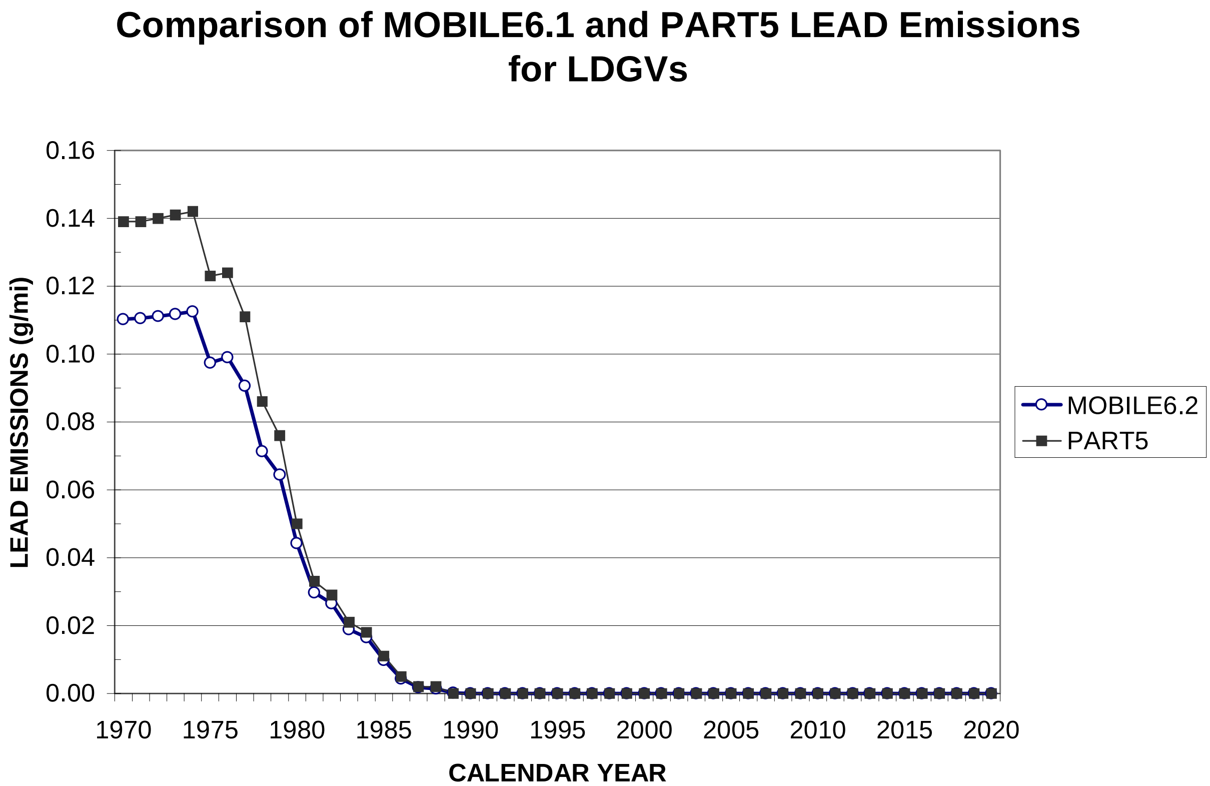

MOBILE6.1 GASPM Emissions Versus
PART5 Carbon Emissions for LDGVs
GASPM (g/mi)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE62
PART5

**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
LEAD EMISSIONS (g/mi)
0.16
0.14
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
MOBILE6.2
PART5

## Figure 5

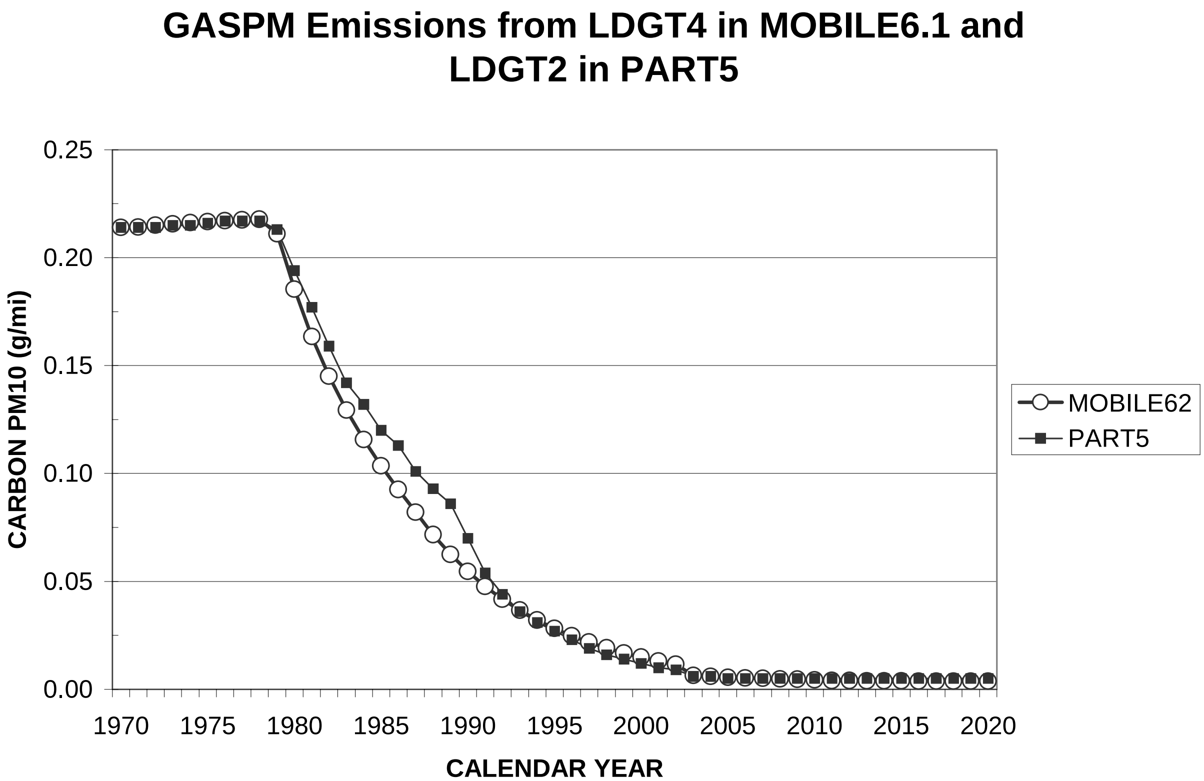

GASPM Emissions from LDGT4 in MOBILE6.1 and LDGT2 in PART5
0.25
0.20
0.15
0.10
0.05
0.00
CARBON PM10 (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE62
PART5

**Figure 6**

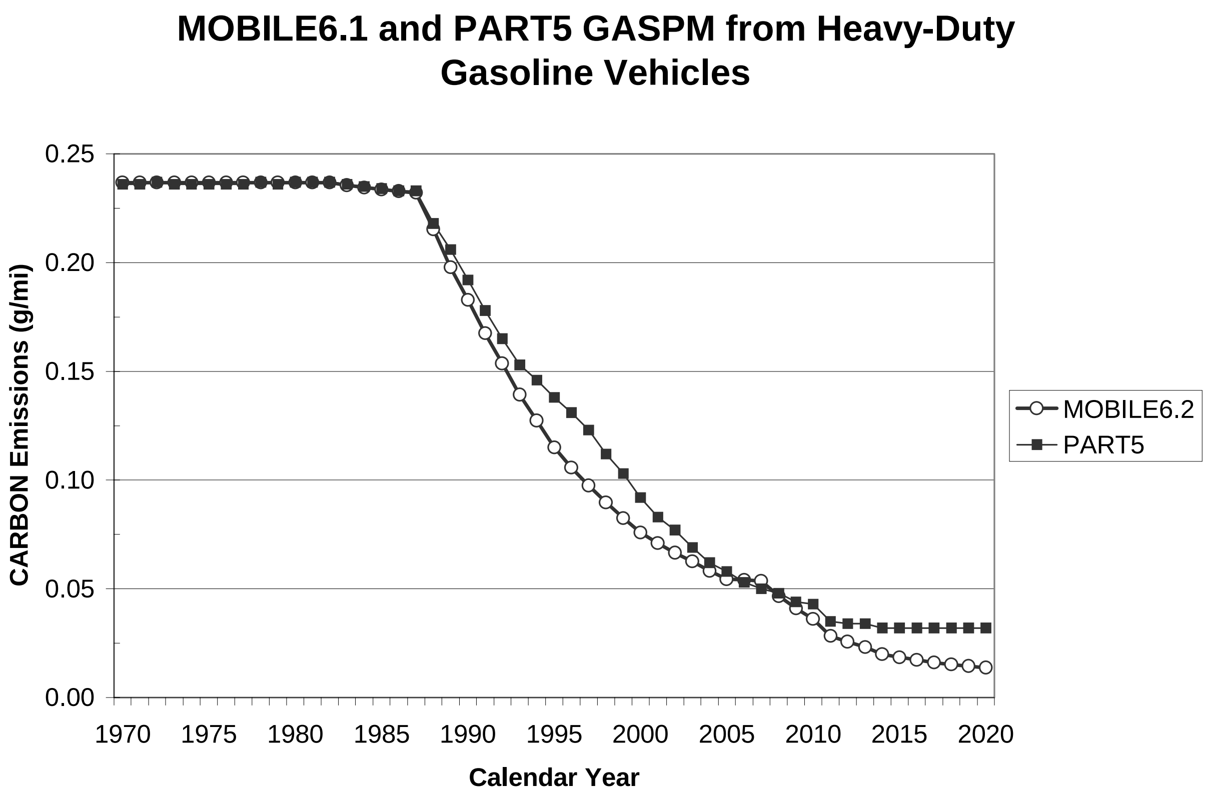

MOBILE6.1 and PART5 GASPM from Heavy-Duty Gasoline Vehicles
0.25
0.20
0.15
0.10
0.05
0.00
CARBON Emissions (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

**Figure 7**

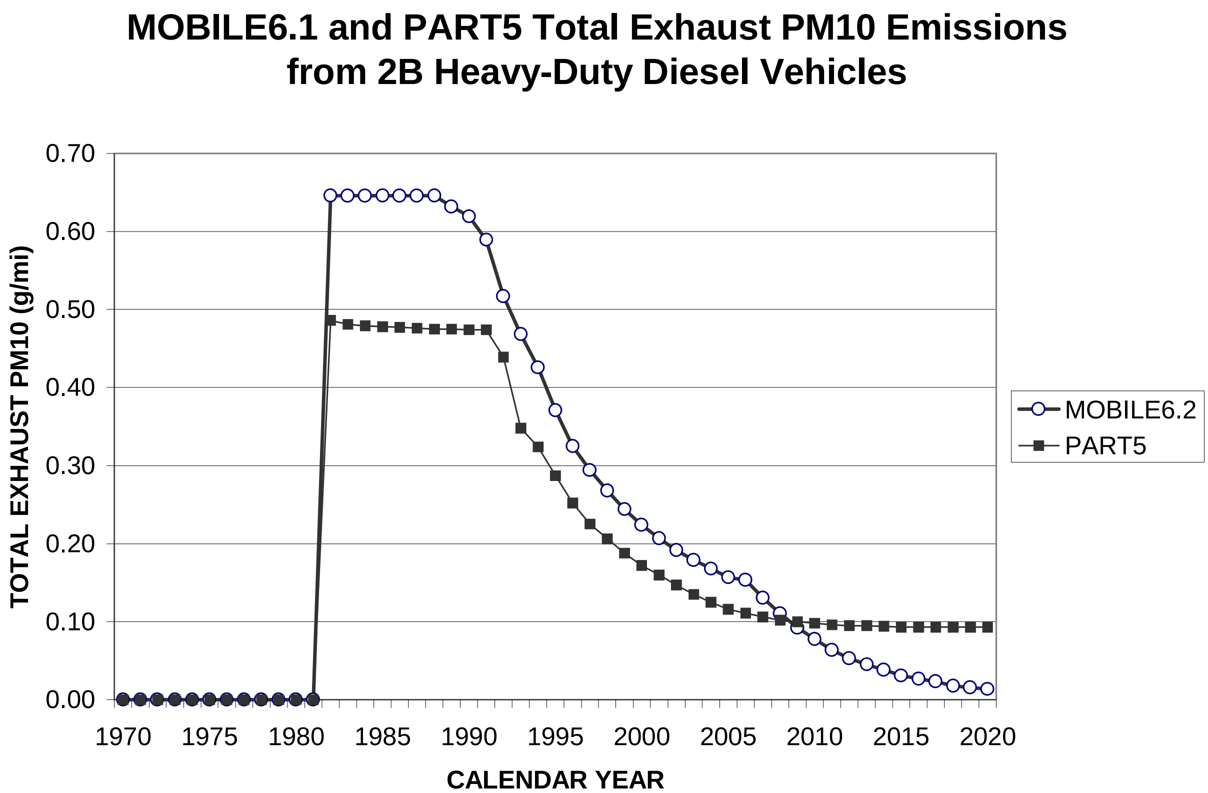
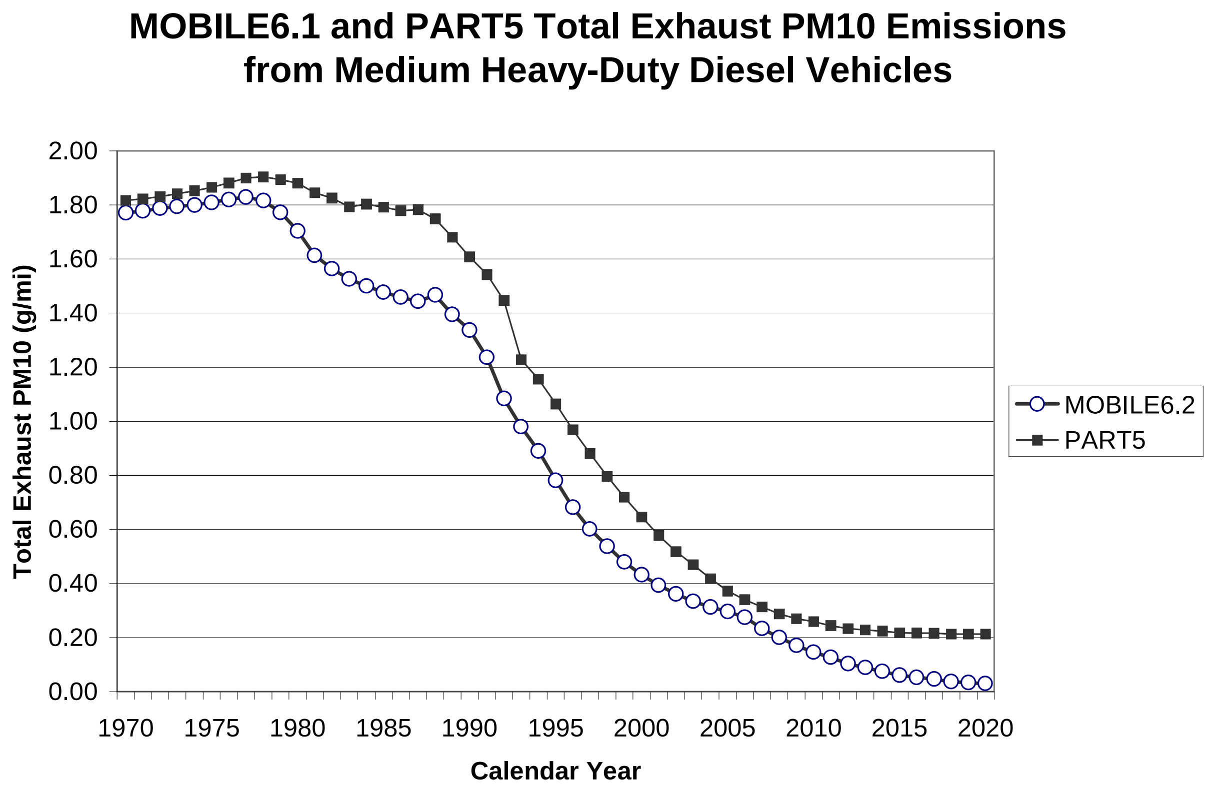
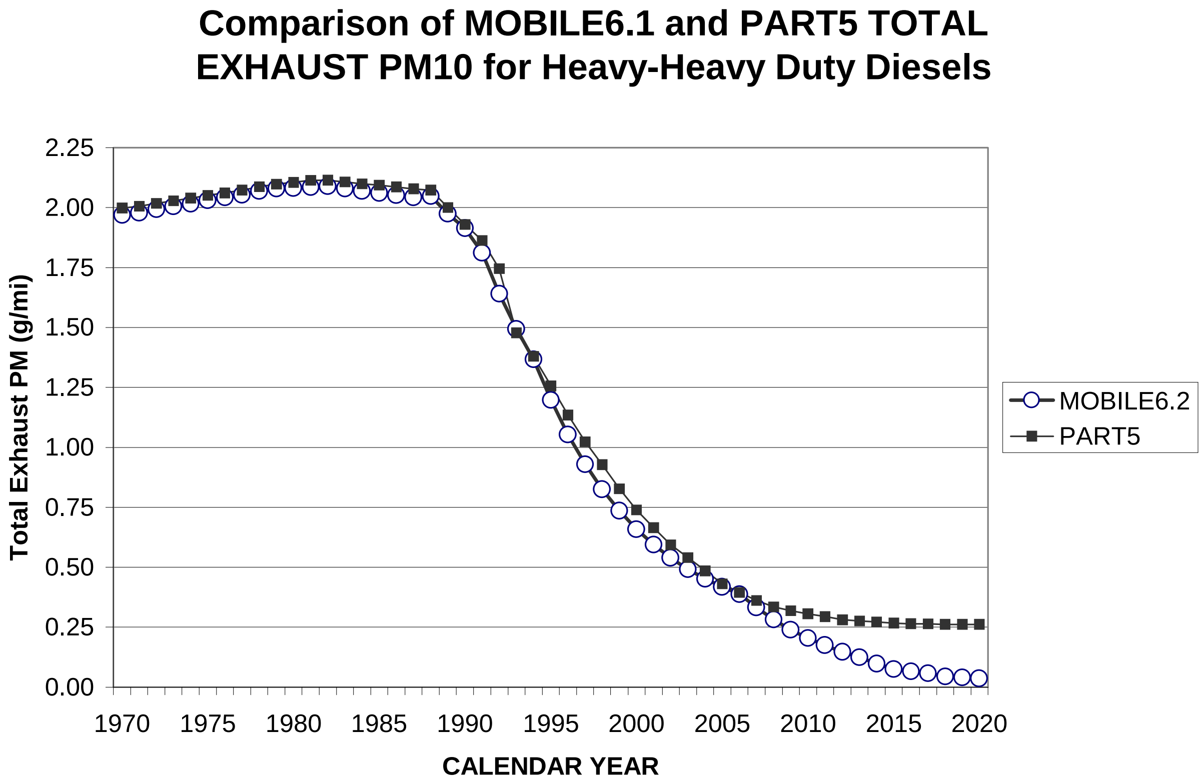

MOBILE6.1 and PART5 Total Exhaust PM10 Emissions
from 2B Heavy-Duty Diesel Vehicles
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
TOTAL EXHAUST PM10 (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

**Figure 8**



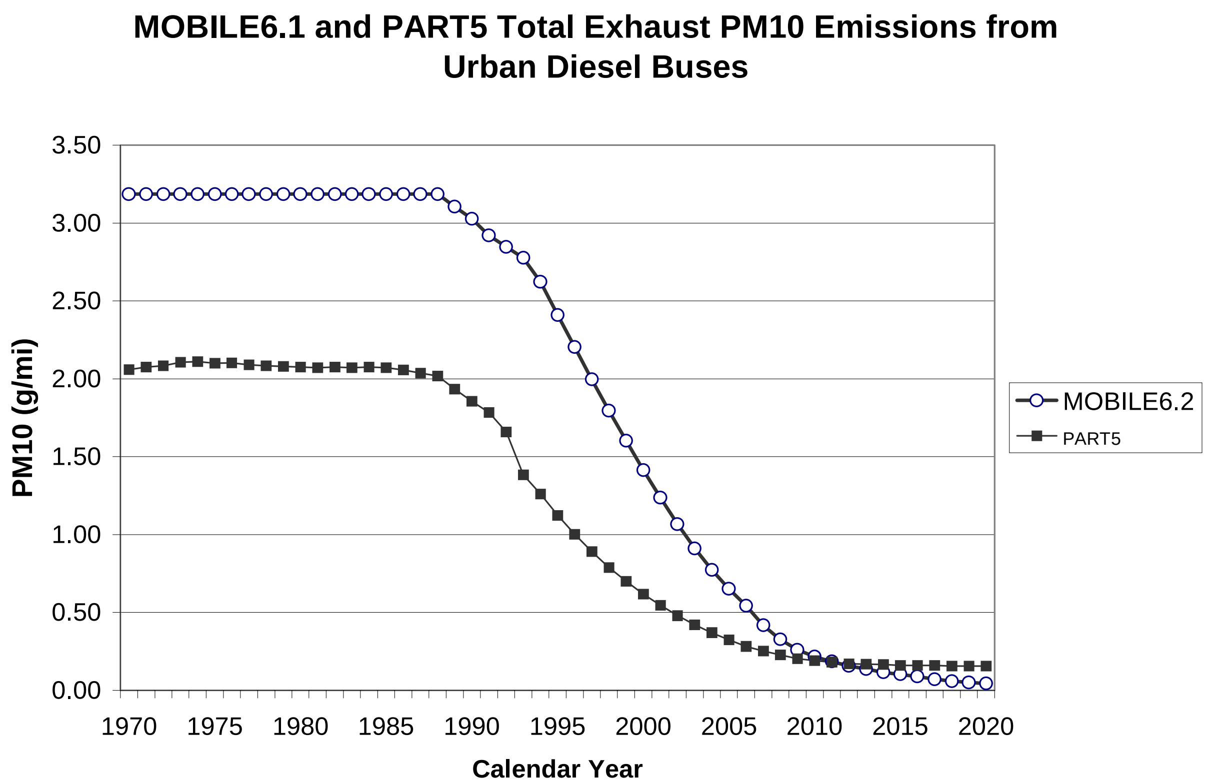
MOBILE6.1 and PART5 Total Exhaust PM10 Emissions
from Medium Heavy-Duty Diesel Vehicles
Total Exhaust PM10 (g/mi)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

**Figure 9**

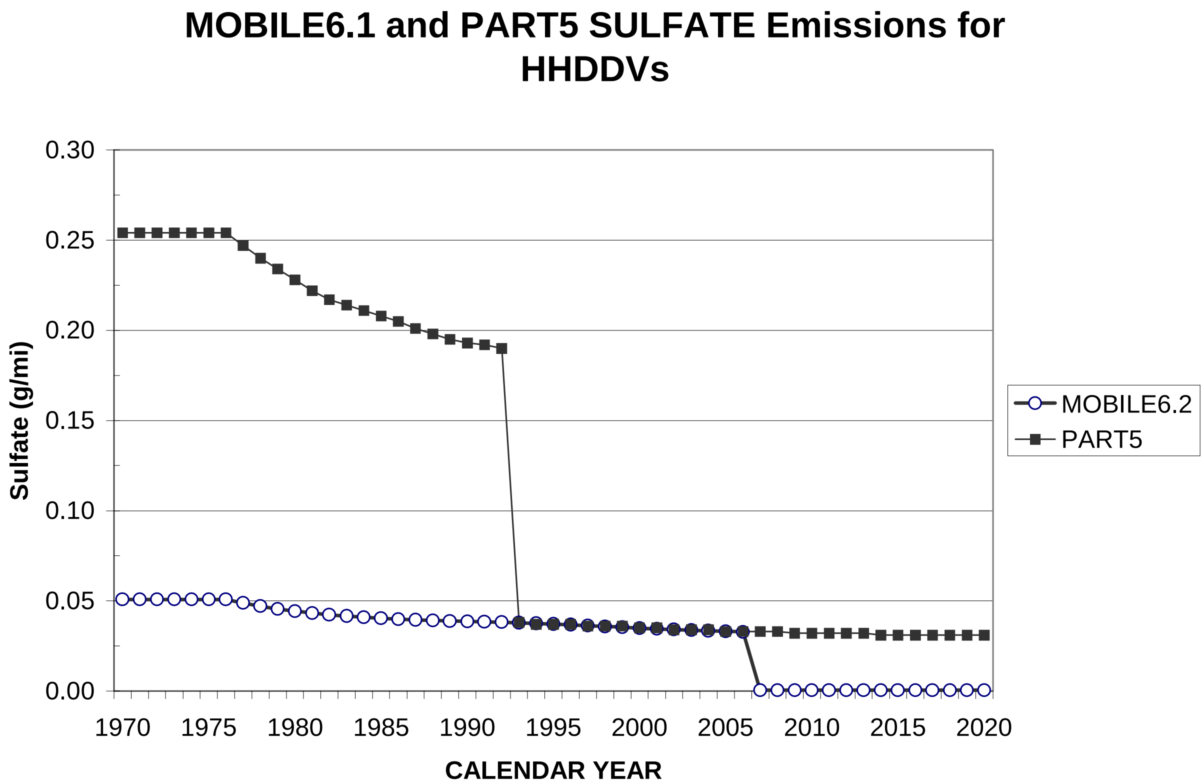


Comparison of MOBILE6.1 and PART5 TOTAL EXHAUST PM10 for Heavy-Heavy Duty Diesels
Total Exhaust PM (g/mi)
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

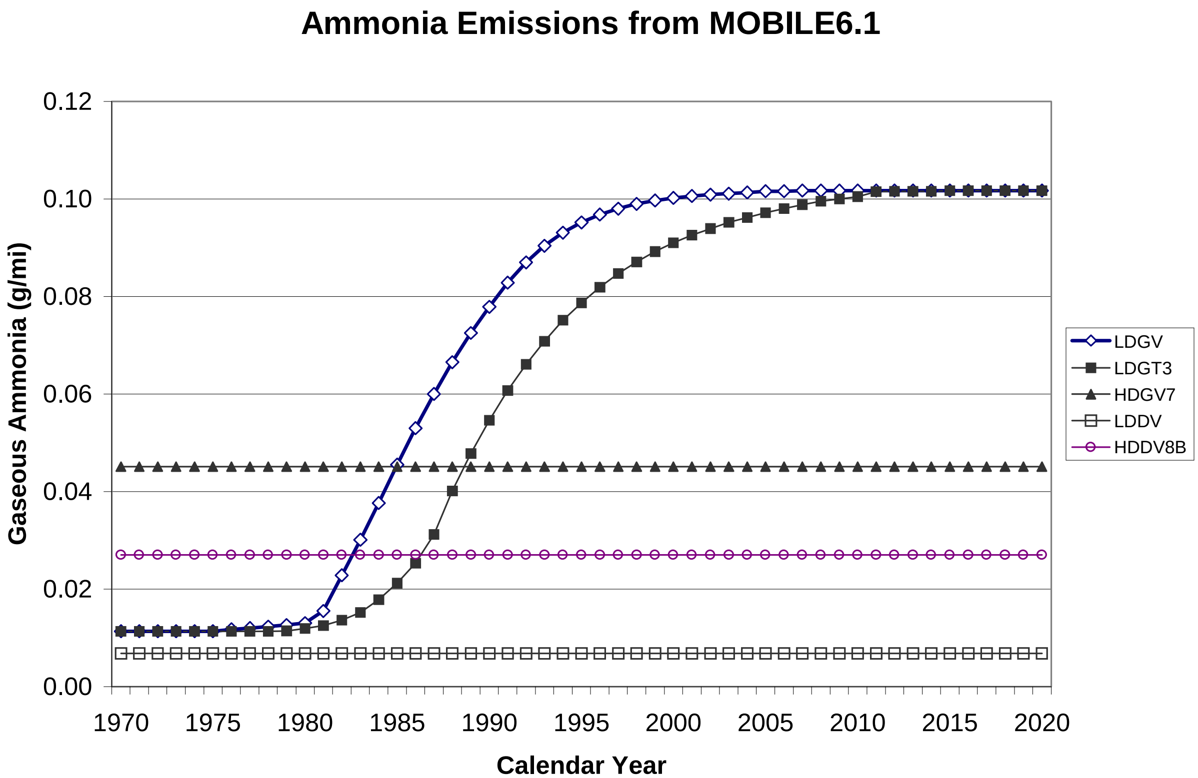
# Figure 10


MOBILE6.1 and PART5 Total Exhaust PM10 Emissions from Urban Diesel Buses
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
PM10 (g/mi)
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
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Sulfate (g/mi)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
CALENDAR YEAR
MOBILE6.2
PART5

# Figure 12


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

## Figure 13

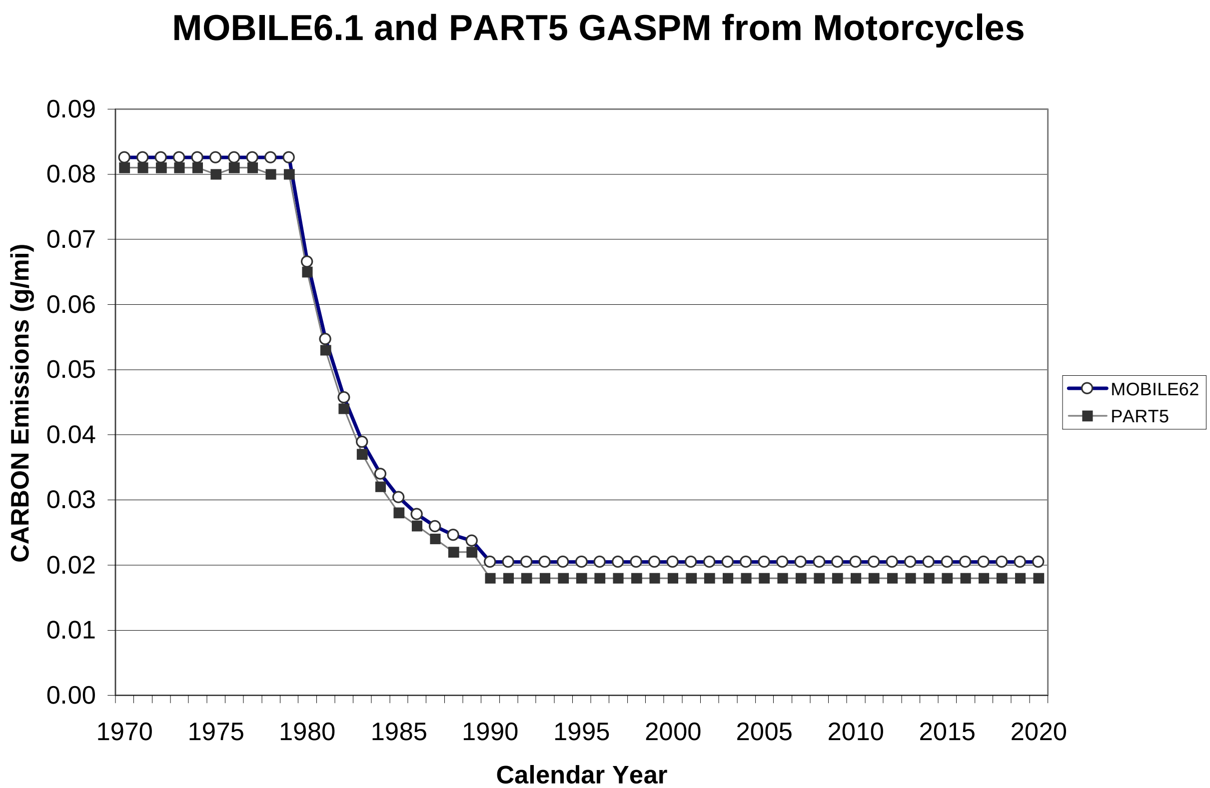

MOBILE6.1 and PART5 GASPM from Motorcycles
CARBON Emissions (g/mi)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE62
PART5

**Figure 14**

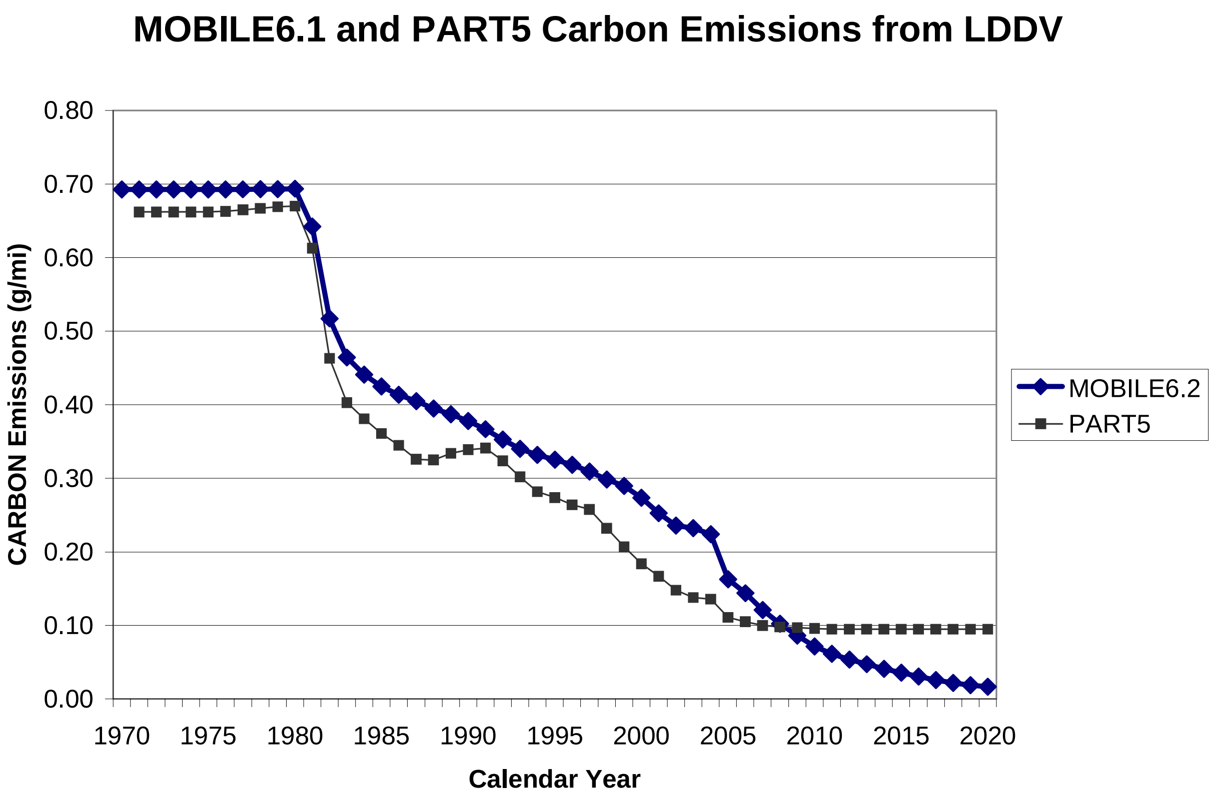
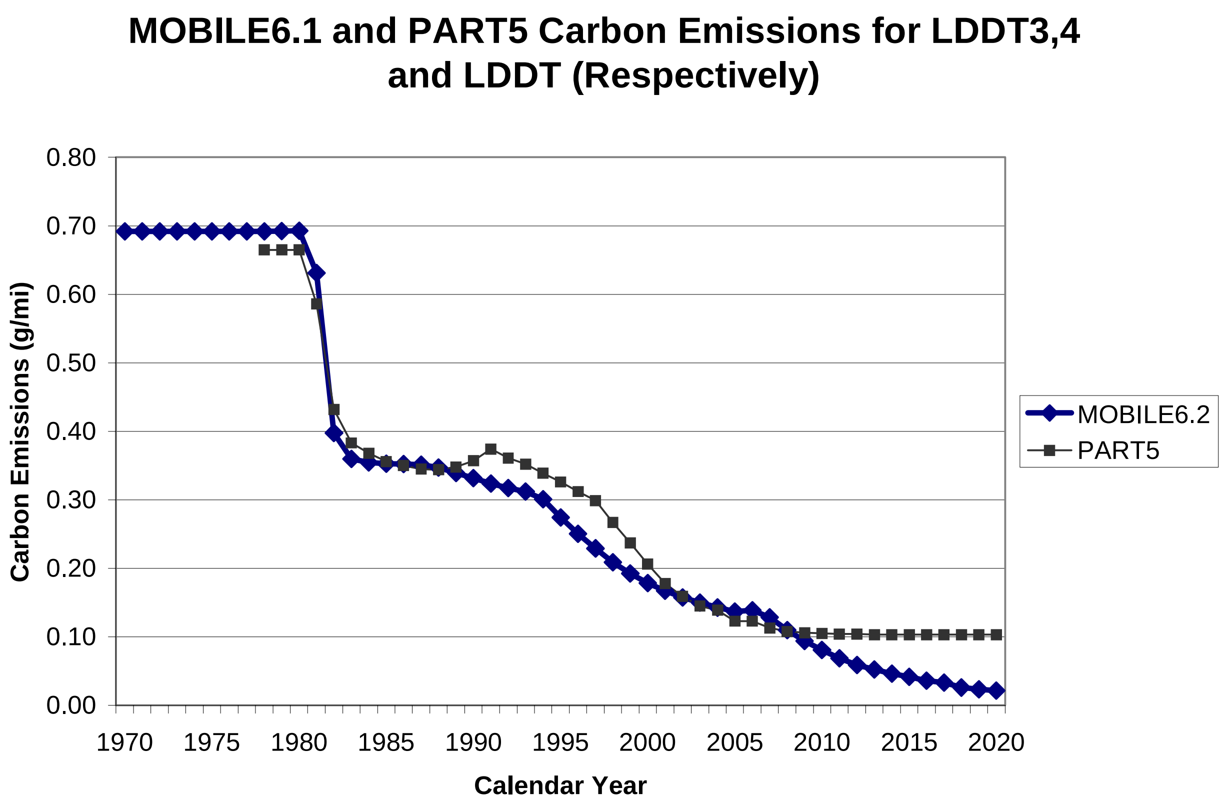
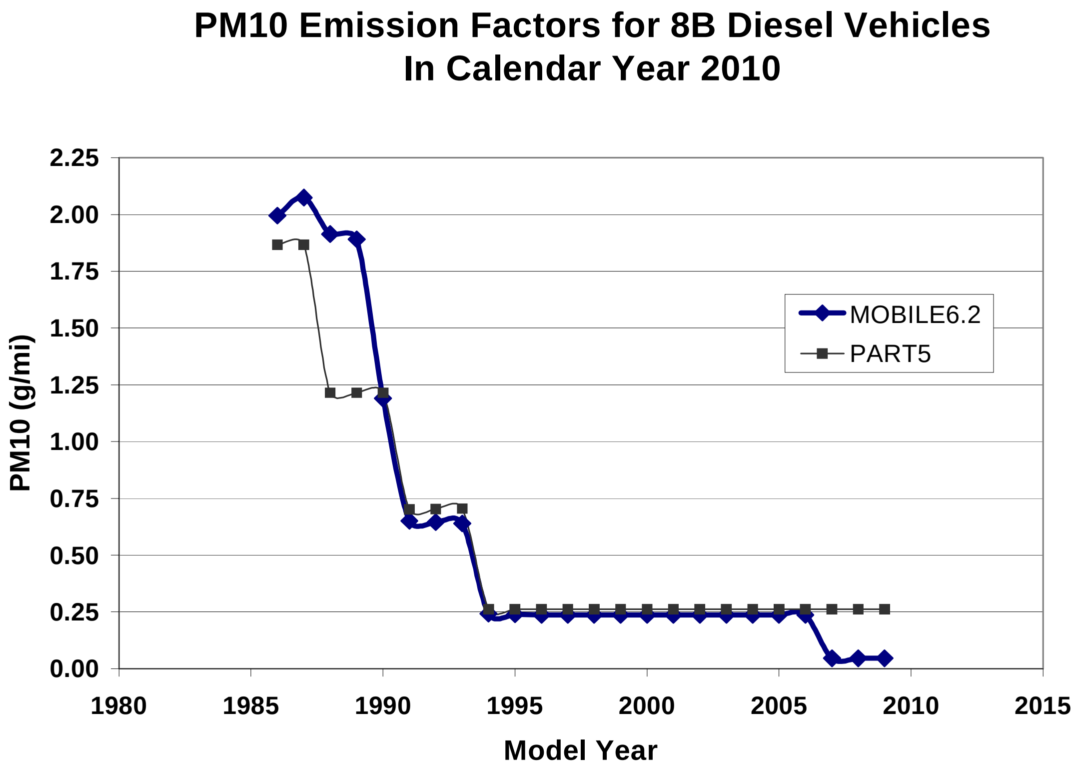

MOBILE6.1 and PART5 Carbon Emissions from LDDV
CARBON Emissions (g/mi)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Calendar Year
MOBILE6.2
PART5

**Figure 15**



MOBILE6.1 and PART5 Carbon Emissions for LDDT3,4 and LDDT (Respectively)
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 16**


PM10 Emission Factors for 8B Diesel Vehicles
In Calendar Year 2010
PM10 (g/mi)
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1980
1985
1990
1995
2000
2005
2010
2015
Model Year
MOBILE6.2
PART5