The Massachusetts
2002 Diesel Particulate Matter Inventory

Massachusetts Department of Environmental Protection

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Executive Summary

Diesel engines are a vital part of our national and state economy, transporting the goods and powering the equipment that help us carry out our daily existence. However, the particulate matter (PM) associated with the exhaust from diesel engines can be harmful to our health in several ways, from short-term effects, such as coughing and exacerbating asthma, to long-term effects, such as respiratory damage and the possibility of developing cancer. In response to these public health concerns, the Massachusetts Department of Environmental Protection (MassDEP) developed *The Massachusetts 2002 Diesel Particulate Matter Inventory,* which reports on the number of diesel-fueled engines in Massachusetts and their diesel PM emissions. The inventory will be used to help identify potential strategies to reduce diesel PM emissions and thereby limit exposure by residents and workers to diesel PM in Massachusetts.

This inventory presents data on diesel $PM_{2.5}$, which represents PM less than or equal to 2.5 microns in diameter, and coarse PM, which represents PM over 2.5 microns to 10 microns in diameter. MassDEP identified the number and PM emissions of the following engine sectors in 2002:

- **On-road engines**, such as automobiles, trucks, and buses that travel on public and private roads
- **Off-road, land-based diesel engines,** such as construction and mining equipment, commercial diesel engines, and industrial equipment
- **Marine engines**, such as recreational and commercial engines (e.g., whale watching boats and fishing vessels)
- **Locomotive engines**, such as those used in commuter rail trains and switchyard trains operating in train yards
- **Diesel stationary engines**, such as turbines that are used at power, chemical, and manufacturing plants to generate electricity and to power pumps and compressors
- **Area source engines**, which are small engines that emit small amounts of pollution individually but may be significant emitters collectively

MassDEP estimated diesel PM emissions for calendar year 2002 to be consistent with the *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia* produced by MassDEP in June 2006. MassDEP developed the *Baseline Emission Inventory* in response to the federal Clean Air Act, which required MassDEP to create an emissions inventory of ozone, carbon monoxide (CO), PM (all sources, including diesel-fueled sources), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and lead if an area or areas in a state fails to attain one or more of the National Ambient Air Quality Standards (NAAQS) for these pollutants. Massachusetts is currently in nonattainment of the eight-hour NAAQS standard for ozone and in attainment of the 1997 NAAQS standard for $PM_{2.5}$. In 2008, the state will receive its designation for the new federal $PM_{2.5}$ standard adopted in 2006.

Primary data sources for this diesel PM inventory included the Massachusetts Enhanced Emissions and Safety Test Program's Vehicle Inspection Database (VID), the *Baseline Emission Inventory* developed by MassDEP, the Massachusetts Office of Law Enforcement, the Massachusetts Division of Marine Fisheries, MassDEP's Stationary Source Emission Inventory System, the U.S.

Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers, the U.S. Census Bureau, and the U.S. Coast Guard.

E.1. Number of Diesel Engines

In 2002, there were approximately 686,000 diesel engines operating in Massachusetts. This number included:

- **121,476 on-road diesel engines** registered in Massachusetts and an estimated 481,000 diesel engines traveling through Massachusetts from other states. It also included 8,500 school buses (gas and diesel); 4,100 private and public transit buses; and up to 1,900 waste collection vehicles;

- **72,000 off-road, land-based engines**, including 29,000 construction and mining engines;

- **259 diesel locomotive engines**, including 216 line-haul/passenger locomotives and 43 switchyard engines;

- **10,300 marine diesel engines**, including 7,300 diesel recreational vessels and 3,000 commercial marine vessels;

- **1,100 stationary diesel engines,** including turbines, reciprocating engines, co-generating turbines, and co-generating reciprocating engines; and,

- **379 diesel area source engines**, which consisted solely of diesel-powered engines used by roofing contractors to heat asphalt before applying it to residential or commercial roofs.

Figure E-1 displays the percentage of engines in each sector when out-of-state engines are included in the data. Out-of-state engines are clearly the largest group of diesel engines traveling in Massachusetts. The 205,000 diesel engines registered in Massachusetts represented only 30% of all the diesel engines operating in the state in 2002.

Figure E-1.
Percent of Diesel-Powered Engines in Massachusetts in 2002
Including Out-of-State On-Road Engines (Total = 686,445 Engines)

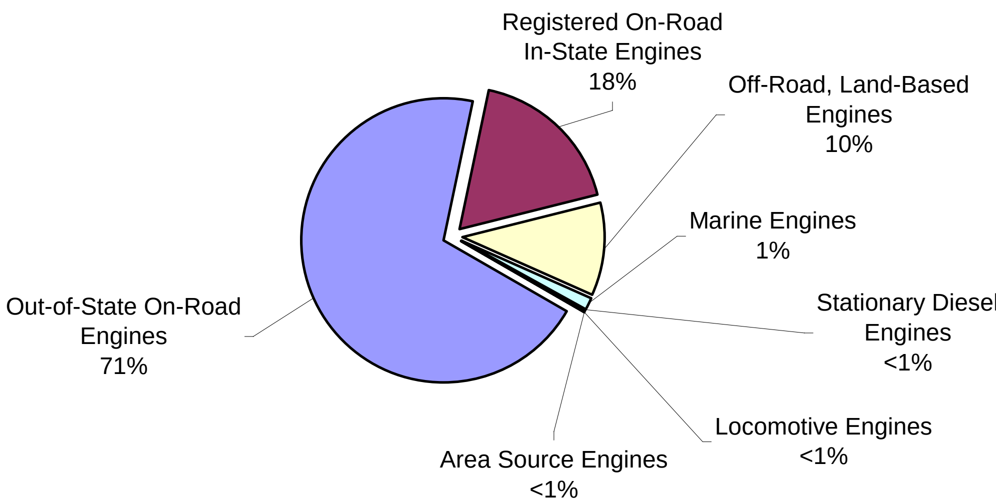
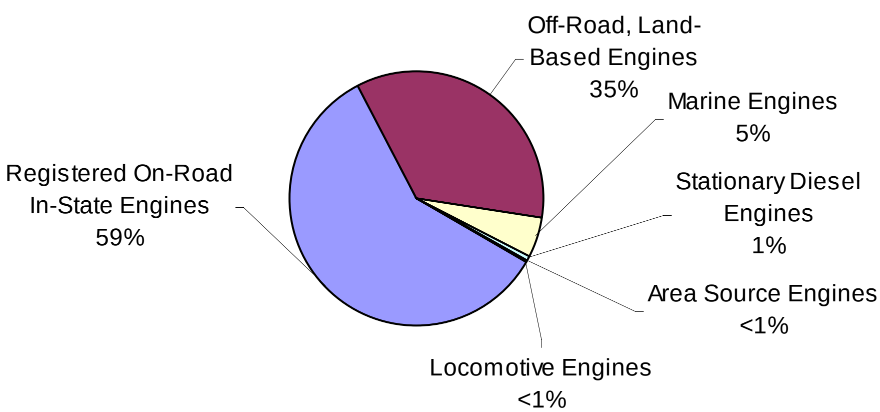


Figure E-2 shows the percentage for each engine sector, excluding out-of-state engines. In this scenario, on-road engines represented nearly 60% of the engine force; off-road, land-based engines represented the other significant portion, with 35% of the state's diesel engines.

Figure E-2.
Percent of Diesel-Powered Engines in Massachusetts in 2002
Excluding Out-of-State On-Road Engines (Total = 205,445 Engines)



E.2. Emission Standards and the Age of Diesel Engines

In the late 1990s and the early 2000s, EPA strengthened emission standards for PM in the on-road, off-road, marine, locomotive and stationary engine sectors. On-road and off-road, land-based engines must now meet Tier 4 emission standards for PM (0.01 grams/brake horsepower-hour and a range of 0.02 g/bhp-hr to 0.30 g/bhp-hr, respectively). EPA has also proposed regulations for Tier 4 PM emission standards for marine and locomotive engines. At the same time, EPA promulgated new sulfur limits on diesel fuel, reducing the sulfur levels from 500 ppm to 15 ppm for on-road vehicles in 2006, and from 3,000 to 15 ppm for off-road, marine, locomotive and stationary diesel engines over several years.

For the year 2002, nearly 70% of diesel on-road engines in Massachusetts were running on the cleanest PM emission standard available at the time (0.10 g/bhp-hr). However, as many as 16% of on-road diesel engines—12,900 vehicles—were operating without any PM emission standard at all. Similarly, of the 8,500 school buses in operation, up to 19% had no PM emission controls at all or were emitting PM at a higher level. Although the data are limited, the picture is the same for marine and locomotive engines. Data indicate that 85% of the 1,900 marine vessels analyzed were not manufactured to meet any emission standards while a small sample indicates that at least some locomotive engines also do not meet any emission standards. Due to the fact that PM emission standards for stationary diesel engines took effect for 2006, it is estimated that the majority of the engines were not manufactured to a PM emission standard. Model year data specific to Massachusetts off-road, land-based engines and area source engines are unavailable.

E.3. PM Emissions of Diesel Engines

Diesel engines released an estimated 4,000 tons of $PM_{2.5}$ in 2002. Collectively, diesel off-road land-based engines and on-road diesel engines emitted 89% of all diesel $PM_{2.5}$ emissions. Of the six diesel engine sectors MassDEP analyzed,

- **On-road diesel engines emitted the most diesel $PM_{2.5}$ in 2002,** with 1,860 tons or 46% of statewide diesel $PM_{2.5}$ emissions.

- **Off-road, land-based diesel engines generated a significant amount of $PM_{2.5}$ as well**, with 1,726 tons or 43% of statewide diesel $PM_{2.5}$ emissions.

- **Marine and locomotive engines emitted less than 10% of diesel $PM_{2.5}$.** Marine engines emitted approximately 250 tons, representing 6% of statewide diesel $PM_{2.5}$ emissions. Locomotive engines emitted 142 tons, representing 4% of the total diesel $PM_{2.5}$ in Massachusetts.

- **Stationary sources emitted only 32 tons or 0.8% of statewide diesel $PM_{2.5}$ emissions in 2002**. Area source engines, with emissions of 10 tons or 0.3% of statewide diesel $PM_{2.5}$ emissions, emitted a small amount of diesel $PM_{2.5}$ as well.

As shown in Figure E-3, the following five engine groups emitted the most diesel $PM_{2.5}$ in 2002:

- **On-road heavy-duty diesel vehicles weighing 26,001 lbs. or more** (1,587 tons or 40% of all $PM_{2.5}$), such as 18-wheelers, cement trucks, and moving trucks;

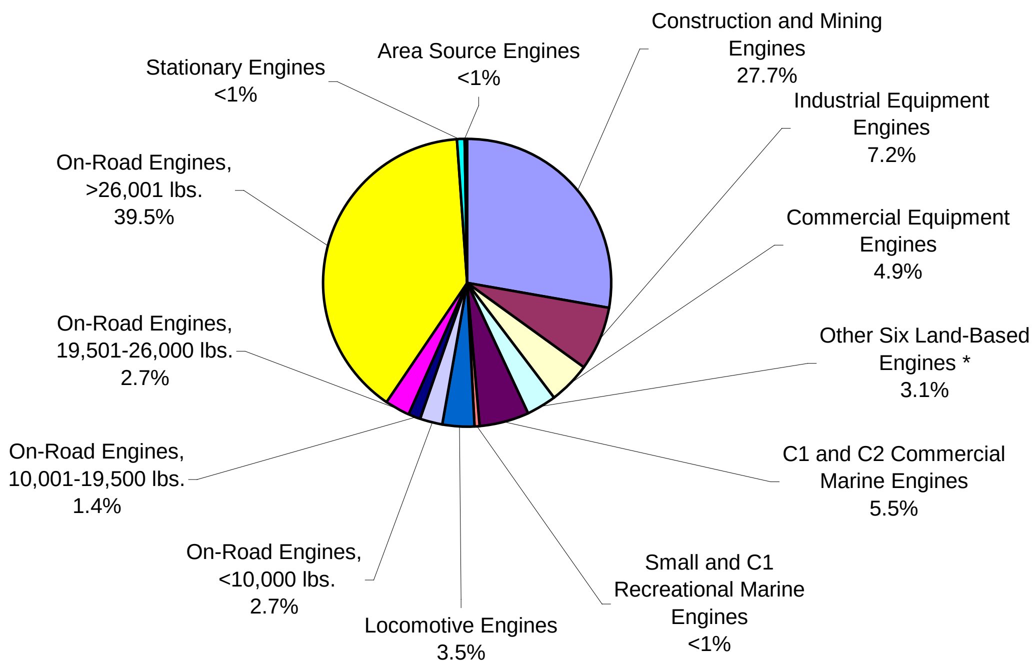
- **Construction and mining equipment engines** (1,113 tons or 28% of all $PM_{2.5}$), such as bulldozers, excavators and cranes;

- **Industrial equipment engines** (289 TPY or 7% of all $PM_{2.5}$), such as forklifts, sweepers/scrubbers, and tractors;

- **C1 and C2 commercial marine engines** (222 tons or 6% of all $PM_{2.5}$), such as police boats, commercial fishing vessels, whale watching boats, passenger ferries and tugboats;

- **Commercial equipment engines** (198 tons or 5% of all $PM_{2.5}$), such as compressors, generators, pressure washers, and pumps.

Figure E-3.
Diesel PM2.5 Emissions, All Massachusetts Sources, Detail
(Percent of 4,017 Tons)



* Agricultural equipment, airport ground support equipment, commercial lawn and garden equipment, logging equipment, railroad equipment, and recreational equipment

In addition, although MassDEP estimated emissions for the sectors in several ways, this inventory identified average per engine emissions across sectors:

- **Locomotives had the highest per engine $PM_{2.5}$ emissions, based on the number of engines and their estimated PM emissions**. C1 and C2 commercial marine engines also had somewhat high per engine emissions.

- **On-road diesel engines, the sector with the most number of engines, had the lowest average per engine PM emissions**.

Finally, almost all the diesel PM emitted in Massachusetts in 2002 was $PM_{2.5}$ (93%). Coarse PM represented only 7% of PM_{10} emissions. Of the six engine sectors, stationary diesel engines emitted the most coarse PM (51%); however, this was still only 31 tons. Locomotive engines also emitted a substantial amount of coarse PM (22% or 40 tons).

With the recent federal mandate for ULSD fuel and new $PM_{2.5}$ standards for on-road and off-road diesel engines promulgated by EPA, total $PM_{2.5}$ emissions from diesel trucks, buses and off-road equipment are estimated to decrease by 80 percent in 2030 compared to 2000 levels. These national emission standards will improve air quality in Massachusetts and help protect the health of its workers and citizens. However, it should be noted that all forms of diesel engines, from recreational marine vessels to off-road construction and mining equipment, will continue to emit $PM_{2.5}$ at less restrictive emission levels and in some cases, with no emission limits at all (e.g., pre-1996 model year construction equipment). This represents a significant challenge in protecting the health of workers and the public for the near future until the regulations to decrease $PM_{2.5}$ emissions are fully implemented. The information contained in this inventory will therefore be useful in identifying those engines to target for emission reductions to decrease the health effects of diesel $PM_{2.5}$ on the public.

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Acronyms

ALAPCO	Association of Local Air Pollution Control Officials
NACAA	National Association of Clean Air Agencies
C1	Category 1 marine engine
C2	Category 2 marine engine
C3	Category 3 marine engine
CARB	California Air Resources Board
CFR	Code of Federal Regulations
CMR	Code of Massachusetts Regulations
CO	carbon monoxide
D/l	Displacement/liter
DMF	Division of Marine Fisheries (Massachusetts)
EPA	Environmental Protection Agency (U.S.)
FR	Federal Register
FHWA	Federal Highway Administration
g/bhp-hr	grams per brake horsepower-hour
g/mi	grams per mile
GVWR	gross vehicle weight rating
HC	hydrocarbons
HDDV	heavy-duty diesel vehicle
hp	horsepower
kW/hr	kilowatts per hour
LDDV	light-duty diesel vehicle
LDGT	light-duty gas truck
LDGV	light-duty gas vehicle
LSD	low sulfur diesel
MANE-VU	Mid-Atlantic and Northeast Visibility Union
MBTA	Massachusetts Bay Transportation Authority
MDO	marine diesel oil
MHD	Massachusetts Highway Department
mph	miles per hour
NAAQS	National Ambient Air Quality Standards
NESCAUM	Northeast States for Coordinated Air Use Management
NH_3	ammonia
NOx	nitrogen oxides
NSPS	New Source Performance Standards
OLE	Office of Law Enforcement (Massachusetts)
ppm	parts per million
PM	particulate matter
RMV	Registry of Motor Vehicles
RO	residual oil
RTA	Regional Transit Authority
SO_2	sulfur dioxide
SSEIS	Stationary Source Emissions Inventory System
STAPPA	State and Territorial Air Pollution Program Administrators
TPD	tons per day
TPY	tons per year
UCS	Union of Concerned Scientists

ULSD	ultra low sulfur diesel
USCG	U.S. Coast Guard
VID	Vehicle Inspection Database
VIUS	Vehicle Inventory and Use Survey
VMT	vehicle miles traveled
VOCs	volatile organic compounds

1.0. Introduction

Diesel fuel is an important part of our state and national livelihood. Diesel fuel powers much of the heavy equipment, 18-wheelers, school buses, generators, and other vehicles and engines that are vital to our daily existence and active economy. However, the exhaust from diesel-fueled vehicles can be harmful to our health in several ways, from short-term effects, such as coughing and exacerbating asthma, to long-term effects, such as respiratory damage and the possibility of developing cancer.

In response to these serious health effects, the Massachusetts Department of Environmental Protection (MassDEP) has developed *The Massachusetts 2002 Diesel Particulate Matter Inventory.* This inventory provides data on the number of diesel-fueled engines in the state and their emissions of diesel particulate matter (PM), the primary pollutant of concern of diesel exhaust. It will be used to help MassDEP and MassDEP's parent agency, the Executive Office of Energy and Environmental Affairs (EOEEA), identify potential strategies to reduce diesel PM emissions and thereby limit exposure by residents and workers to diesel PM in Massachusetts.

1.1. Fine vs. Coarse Particulate Matter

PM consists of dust, dirt, soot, fly ash, and smoke and is a mixture of microscopic and visible solid particles and minute liquid droplets known as aerosols. PM is generated by natural sources, such as dust from unpaved roads and fires, and anthropogenic sources, such as emissions from on-road and off-road vehicles, power plants, and space heaters. PM encompasses primary PM, which is directly emitted into the air from cars, trucks, forest fires, unpaved roads and construction sites, and secondary PM, which forms indirectly from the transformation of certain gases emitted into the atmosphere.

The diesel PM of greatest health concern is categorized as fine and ultra fine PM. In Massachusetts, many sources combusting diesel fuel, such as highway trucks, transit buses, school buses, and many kinds of marine engines, emit almost exclusively fine PM, or PM that is 2.5 microns or less in diameter ($PM_{2.5}$). Fires and dust from natural sources generate coarse PM, or PM that is greater than 2.5 and up to, and including, 10 microns in diameter. $PM_{2.5}$ and coarse PM are subsets of PM_{10}, which is all PM than is 10 microns or less in diameter. Locomotives and stationary engine sources, such as electric utility power plants, are two diesel sources that emit a significant amount of coarse and $PM_{2.5}$ in this state.

Due to the health effects associated with $PM_{2.5}$ from the combustion of diesel fuel, this inventory report focuses primarily on $PM_{2.5}$ that is emitted from diesel-powered sources.

1.2. Health Effects of Diesel $PM_{2.5}$

Health and environmental officials are particularly concerned with $PM_{2.5}$ because these fine particles can be inhaled more easily than coarse PM and can lodge deep in the lungs. The U.S. Environmental Protection Agency (EPA) has identified diesel $PM_{2.5}$ as a probable carcinogen and the California Air Resources Board (CARB) has classified diesel exhaust as a toxic air contaminant based on its carcinogenic and other health effects.[1] Studies have not found a safe exposure level for $PM_{2.5}$; in other words, exposure to even small amounts of $PM_{2.5}$ is associated with adverse health effects.[2]

Exposure to PM has been causally linked with increased mortality from cardiopulmonary diseases and lung cancer. Studies show that heart attacks may be linked with very brief exposures of less than 24 hours. Other health effects include lung damage, respiratory distress, and exacerbation of bronchitis and existing allergies. Population groups that are especially susceptible to the health effects associated with PM exposure include the elderly, children and people with existing heart disease, lung disease and diabetes.

In Massachusetts, $PM_{2.5}$ is also a serious public health concern because it is thought to be associated with the state's high rate of asthma.[3] The Asthma Regional Council, in the most comprehensive examination of asthma in New England to date, recently found that one in ten children in Massachusetts has asthma.[4] Children are more vulnerable to air pollution than healthy adults because their respiratory systems are still developing and they have a faster breathing rate. Other factors that may also increase vulnerability to pollution-related effects include reduced access to health care and specific exposure pathways, such as the proximity of residences to PM sources (e.g., roadways and construction sites).

1.3. Environmental Effects of Diesel $PM_{2.5}$

$PM_{2.5}$ reduces visibility in the atmosphere. According to EPA, the range of natural visibility undisturbed by air pollution in the eastern United States is 90 miles. However, due to the haze created by air pollution, that range is currently only 14 to 24 miles. In addition, PM from diesel-fueled engines can affect cloud cover, resulting in significant atmospheric warming.[5]

Diesel PM can persist in the environment and get into the food chain, potentially causing adverse effects to aquatic and soil ecological receptors.[6] PM can also affect human populations and ecosystems far removed from any PM source. For example, PM can have an environmental lifetime of one to three weeks with the potential to travel long distances on prevailing winds to isolated communities during that time. PM has been found at the South Pole, where no major emission source exists for thousands of miles.[7] Increased diesel PM in urbanized areas can also cause increased deposition and blackening of building structures. This effect is particularly evident at locations with increased concentrations of diesel engines, such as bus depots and train stations.

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[1]California Air Resources Board, Stationary Source Division, Mobile Source Control Division, *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles*, October 2000.
[2]Melinda D. Treadwell, "Diesel Emissions: Environmental, Occupational, and Public Health Impacts." (Northeast States for Coordinated Air Use Management: Keene State College, Sept. 23, 2003).
[3]The New England Asthma Regional Council (ARC). Available on-line at: http://www.asthmaregionalcouncil.org/actionplan/actionplan.html.
[4]ARC, "The Burden of Asthma in New England: A Report by the Asthma Regional Council," March 2006.
[5]J. Hansen, M. Sata, R. Ruedy, A. Lacis, and V. Oinas., "Global Warming in the Twenty-First Century: An Alternative Scenario" (Proceedings of the National Academy of Sciences June 2000).
[6]U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, "Health Assessment for Diesel Engine Exhaust" (EPA/600/8-90/057F, May 2002).
[7]Lance Frazer, "Seeing Through Soot," *Environmental Health Perspectives* (Vol. 110 (8): 470-A473 August 2002).

1.4. Diesel Emission Sources Included in this Inventory

This report presents inventory and emissions data on off-road, on-road, stationary and area source engines that burn diesel fuel. Off-road engines consist of land-based mobile engines, marine engines and locomotive engines. On-road engines consist of automobiles, trucks and buses that travel on public and private roads. Area sources are small facilities or engines that emit small amounts of PM individually but are significant emitters collectively. Diesel stationary engines are typically small engines and turbines that are used at power, chemical and manufacturing plants to generate electricity and power pumps and compressors. Examples of diesel engines used in these sectors include:

- **Off-road, land-based diesel engines**: excavators, cranes, forklifts and tree fellers
- **Marine diesel engines**: recreational boats, commuter vessels, whale watching boats, and enforcement vessels
- **Locomotive diesel engines**: line-haul and commuter rail engines and switchyard engines
- **On-road diesel engines**: school buses, transit buses, light-duty diesel passenger vehicles and trucks, such as delivery vehicles, commercial lawn trucks and 18-wheelers
- **Stationary diesel engines**: emergency or backup generators
- **Area source diesel engines**: asphalt roofing engines (this is the only area source that burns diesel fuel)

These engines generally burn one of the several diesel fuels discussed below:

- **No. 1 diesel fuel**, which is used in high-speed diesel engines that generally operate under frequent speed and load changes, such as those in city buses;
- **No. 2 diesel fuel**, which is used in high-speed diesel engines that generally operate under uniform speed and load conditions, such as those in railroad locomotives, trucks and automobiles. Low sulfur No. 2 diesel (sulfur content of 500 parts per million or less) and high sulfur No. 2 diesel (sulfur content above 500 ppm) are part of this category; and,
- **No. 4 diesel fuel**, which is used in low and medium speed diesel engines.[8]

These diesel fuels are part of the broad petroleum category known as distillate fuel oil, which includes six classes of fuel distinguished by boiling point, composition and purpose. The distillate fuel oil category also includes No. 1 fuel oil, which is used in portable outdoor stoves, and No. 2 fuel oil (more commonly known as heating oil), which is used in domestic furnaces. Neither of these fuels is considered a diesel fuel and therefore their $PM_{2.5}$ emissions are not included in this inventory. This inventory also does not address aircraft emissions because aircraft jet fuel is not a diesel fuel. Finally, this inventory does not include emissions resulting from diesel spills. Diesel fuel that is combusted emits $PM_{2.5}$, while diesel fuel that is spilled or otherwise released emits volatile organic compounds (VOCs).

[8]U.S. Energy Information Administration, *Petroleum Marketing Monthly*, (July 2005) 155.

1.5. Data Sources

Primary data sources for this diesel PM inventory included the Massachusetts Enhanced Emissions and Safety Test Program's Vehicle Inspection Database (VID), the Massachusetts Office of Law Enforcement, EPA, the U.S. Army Corps of Engineers, the U.S. Census Bureau, and the U.S. Coast Guard. Data were also acquired through telephone calls, websites, and E-mails.

Another primary source of data was the *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia* ("*Baseline Emission Inventory")*. MassDEP produced the *Baseline Emission Inventory* in response to two separate federal requirements to develop an emissions inventory of PM and other pollutants for 2002. The federal Clean Air Act requires MassDEP to develop an emissions inventory of ozone, carbon monoxide (CO), PM (all sources, including diesel-fueled sources), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and lead if an area (or areas) in a state fails to attain one or more of the National Ambient Air Quality Standards (NAAQS) for these pollutants.

Massachusetts is currently in attainment of the NAAQS for CO and SO_2. The state is in attainment of the PM standard adopted in 1997; however, since a new federal 24-hour standard for PM was adopted in 2006, Massachusetts must submit a recommendation to EPA on whether it is in attainment or nonattainment of the new standard. EPA will issue a final designation on the state's status by December 2008. Eastern and Western Massachusetts are currently in nonattainment of the eight-hour NAAQS standard for ozone. VOCs and NOx are pollutants that form ozone in the presence of sunlight and warm temperatures.

MassDEP also developed the *Baseline Emission Inventory* in response to the federal Consolidated Emissions Reporting Rule (CERR),[9] which requires MassDEP to generate and update every three years an annual inventory of all pollutants that contribute to regional haze in the state. VOCs, NOx, CO, SO_2, PM, and ammonia (NH_3) all contribute to regional haze. Thus, while Massachusetts is in attainment of the NAAQS for CO, SO_2, and $PM_{2.5}$, MassDEP must still develop an inventory of these pollutants under the CERR.

Federal regulations do not require MassDEP to estimate *diesel* $PM_{2.5}$ within the *Baseline Emission Inventory*. As a result, MassDEP produced this diesel $PM_{2.5}$ inventory to estimate diesel $PM_{2.5}$ emissions in response to the health effects associated with diesel $PM_{2.5}$. MassDEP estimated diesel PM emissions for calendar year 2002 to be consistent with the *Baseline Emission Inventory*, which, as the title states, used 2002 as its baseline year. In cases where data for 2002 were unavailable, MassDEP adjusted 2005 and 2006 data retroactively to 2002 levels based on annual growth rates.

1.6. Emissions Methodology

The general methodology used in developing this emission inventory for diesel engines involves the application of activity and emission factors to engine source categories. An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of a pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., pound of $PM_{2.5}$ emitted per ton of diesel fuel burned). In most cases, these factors are simply

[9] 67 *Federal Register* (FR) 39602, June 10, 2002.

averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages of activities or operations in the source category.[10]

More detailed descriptions of the methodologies used to estimate emissions of particular types of sources are included in the various sections of this report.

1.7. Structure of the Report

This report includes the following additional eight sections:

- **Section 2.0. Diesel Engines and $PM_{2.5}$ Emissions in Massachusetts: An Overview**: This section presents data on the number of engines in each sector in 2002 and their amount of diesel PM2.5 emissions, including average per engine $PM_{2.5}$ emissions. Data are also presented on the portion $PM_{2.5}$ is of overall diesel PM_{10} in Massachusetts.

- **Section 3.0. On-Road Diesel Engines**: This section presents data on the largest source of diesel $PM_{2.5}$ emissions in Massachusetts in 2002. Data are presented for in-state and out-of-state on-road vehicles, including trucks, school buses, waste collection vehicles, and public and private transit vehicles. Data are also discussed according to the gross vehicle weight rating (GVWR) of the vehicles (e.g., light-duty, medium-duty and heavy-duty diesel engines).

- **Section 4.0. Off-Road, Land-Based Diesel Engines**: This section presents data on the second largest source of diesel $PM_{2.5}$ emissions in Massachusetts in 2002. Nine equipment groups are discussed, including construction equipment engines, commercial equipment engines, and industrial equipment engines.

- **Section 5.0. Marine Diesel Engines**: This section discusses several categories of marine engines, including commercial and recreational engines.

- **Section 6.0. Diesel Locomotive Engines**: This section presents data on inter-state and intra-state rail lines, including line-haul and commuter rail engines as well as switchyard engines used in rail yards.

- **Section 7.0. Stationary Diesel Engines**: Although there are numerous stationary diesel engines in Massachusetts, this sector only emitted a small percent of diesel $PM_{2.5}$ emissions in 2002. This section discusses these sources.

- **Section 8.0. Area Source Diesel Engines**: This section discusses the one diesel-fueled source in the area source sector: asphalt roofing-kettle engines.

- **Section 9.0. Conclusions**: This section summarizes the data on the number of engines and diesel $PM_{2.5}$ emissions presented in the report.

Each section discusses the number of diesel-fueled engines in the sector, the estimated diesel $PM_{2.5}$ and coarse PM emissions associated with those engines and the sector's existing and future $PM_{2.5}$

[10]MassDEP, *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia,* June 2006.

emission standards. Where available, the inventory also presents data on the age of the engines and growth trends for a particular sector. The sources of data for each engine sector are included at the end of each section. Appendix A includes a summary of all PM emission standards for on-road and off-road diesel engines. Appendix B presents a summary of all the data currently available for these sectors in Massachusetts.

1.8. References for Introduction

California Air Resources Board, Stationary Source Division, Mobile Source Control Division. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October 2000.

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2.0. Diesel Engines and $PM_{2.5}$ Emissions in Massachusetts: An Overview

This section provides an overview of the data for on-road, off-road, land-based engines, marine engines, locomotives, stationary, and area source engines discussed in the other sections. The section presents the total number of engines as well as the total amount of $PM_{2.5}$ emissions in the state in 2002. Numerous sources, including the state Office of Law Enforcement (OLE), the Registry of Motor Vehicles (RMV), EPA, railroad companies, and the U.S. Census Bureau provided data on the number of engines in the various sectors. Using a variety of sources, MassDEP estimated the emissions for on-road engines, locomotives, stationary diesel engines, marine engines and area source engines. EPA estimated the diesel $PM_{2.5}$ emissions of off-road, land-based engines. The remaining sections of this document explain the sources of and assumptions behind the number of engines and emission estimates.

2.1. Total Number of Diesel Engines in Massachusetts

In 2002, over 685,000 diesel-powered engines operated in Massachusetts. The on-road sector had the most diesel-powered engines, with 121,476 engines registered in Massachusetts and an estimated 481,000 engines traveling through Massachusetts from other states. The off-road, land-based engine sector, which includes nine diesel equipment groups,[11] had the next highest number of engines with nearly 72,000 engines. On the other end of the spectrum, there were only 259 diesel locomotive engines and 379 area source engines combusting diesel fuel. Table 2-1 shows the number of diesel engines in each sector operating and/or registered in Massachusetts.

Table 2-1. Number of Diesel-Powered Engines Operating in Massachusetts in 2002

Engine Sector	Number of Engines
Out-of-State On-Road Engines [a]	481,000
Registered On-Road In-State Engines [b]	121,476
Off-Road, Land-Based Engines [c]	71,964
Marine Engines [d]	10,286
Stationary Diesel Engines[e]	1,081
Area Source Engines [f]	379
Locomotive Engines [g]	259
Total	*686,445*

[a] Gus Rankatory, Massachusetts Department of Revenue, 1996.
[b] Massachusetts RMV and MassDEP, Vehicle Inspection Database (VID), 2006.
[c] EPA, 2006.
[d] Massachusetts Division of Marine Fisheries (DMF), 2006; OLE, 2007; U.S. Coast Guard, 2006
[e] MassDEP, Stationary Source Emission Inventory System (SSEIS), 2006.
[f] U.S. Census, 2006.
[g] O'Connell, 2007; Bass, 2007; Culliford, 2007; Rutkowski, 2007; Richardson, 2007; Preissler, no date; McGahan, 2005; Graham, 2007.

Data on the number of diesel engines for marine and stationary engine sectors are inflated because these two sectors also include engines that run on fuel oil, which is a non-diesel fuel. The number of on-road diesel engines is also an overestimate because it includes 2,476 off-road engines that MassDEP was unable to segregate from the on-road data.

[11] Agricultural equipment, airport ground support equipment, commercial equipment, commercial lawn and garden equipment, construction equipment, industrial equipment, logging equipment, railroad equipment, and recreational equipment.

Figures 2-1 shows the percentage each engine group represents of the total number of engines, including out-of-state engines. With 70% of the total, out-of-state vehicles traveling in Massachusetts far outnumbered all other sources of diesel engines—not surprisingly since Massachusetts serves as the northern gateway for the three other New England states and Canada. This means that an enormous number of vehicles are beyond the control of MassDEP since the vehicles are out-of-state.

All together, engines registered in Massachusetts comprised only one-third of the diesel engines. Individually, the two largest sectors were registered on-road in-state engines (18% of the total) and off-road, land-based engines (10%). Stationary, locomotive, marine and area source engines consisted of one percent or less of the total engines in 2002.

Figure 2-2 shows the percentage each engine group represents of the total number of engines, excluding out-of-state engines. Registered on-road vehicles comprised nearly 60% of total in-state engines and off-road, land-based engines made up more than one-third of the total engines in 2002. Marine diesel engines numbered only 5% of the state's engines, even with the extensive Massachusetts coastline and strong fishing industry (many marine engines run on gasoline or other non-diesel fuels).

Table 2-2 shows the data in more detail by engine groups within each sector. When excluding out-of-state engines, the percentages change dramatically for each engine group:

- **On-road diesel engines (based on 121,476 engines) weighing 26,001 lbs. or more had the highest percentage of engines (24%) in 2002**. On-road diesel engines weighing 10,000 lbs. and under also represented a significant part of the inventory (17%).

- **Construction equipment engines, commercial equipment engines, and on-road engines weighing 10,001 to 19,500 lbs. also represented a significant population of diesel engines.** Each of these groups had over 20,000 diesel engines in 2002.

On the other hand, engine groups within the marine diesel engine sector each represented less than 5% of the total inventory. Stationary sources, area sources, and locomotive sources, as noted above, did not have a large number of diesel engines either.

Table 2-2. Number of Diesel-Powered Engines Operating in Massachusetts

Equipment Group	Number of Engines	Percent of Total (Out-of-State Engines Excluded)	Percent of Total (Out-of-State Engines Included)
On-Road Engines [a]			
<10,000 lbs.	35,548	17%	5%
10,001-19,500 lbs.	23,925	12%	3%
19,501-26,000 lbs.	13,378	7%	2%
26,001 lbs. and over	48,625	24%	7%
Off-Road, Land-Based Engines [b]			
Construction and Mining Engines	29,226	14%	4%
Commercial Equipment Engines	22,921	11%	3%
Industrial Equipment Engines	10,679	5%	2%
Six Off-Road Engine Groups [c]	9,138	4%	1%
Marine Engines [d]			
Small and Recreational C1 Engines	7,280	4%	1%
C1 Commercial Engines	2,480	1%	0%
C2 Engines	526	<1%	<1%
Stationary Diesel Engines [e]	1,081	1%	<1%
Area Source Engines [f]	379	<1%	<1%
Locomotive Engines [g]	259	<1%	<1%
Subtotal, Excluding Out-of-State, On-Road Engines	*205,445*	*100%*	*29%*
Out-of-State, On-Road Engines [h]	481,000	--	71%
Total, Including Out-of-State Engines	**686,445**	**--**	**100%**

[a] Massachusetts RMV and MassDEP, VID, 2006.
[b] EPA, 2006.
[c] These include agricultural equipment, airport ground support equipment, commercial lawn and garden equipment, logging equipment, railroad equipment, and recreational equipment.
[d] DMF, 2006; OLE, 2007; U.S. Coast Guard, 2006.
[e] MassDEP, SSEIS, 2006.
[f] U.S. Census, 2006.
[g] O'Connell, 2007; Bass, 2007; Culliford, 2007; Rutkowski, 2007; Richardson, 2007; Preissler, no date; McGahan, 2005; Graham, 2007.
[h] Rankatory, 1996.

Figure 2-3 shows the same data by the percentage of diesel engines in Massachusetts, with out-of-state on-road engines included. Figure 2-4 shows the percentage of on-road engines, excluding out-of-state engines, traveling on Massachusetts's roads.

2.2. Total Amount of Diesel PM Emissions in Massachusetts

Diesel engine sources released 4,017 tons of diesel $PM_{2.5}$ in Massachusetts in 2002. Collectively, diesel off-road, land-based engines and on-road diesel engines emitted 89% of all diesel $PM_{2.5}$, as Figure 2-5 illustrates. In terms of individual sectors:

- **On-road diesel engines emitted the most diesel $PM_{2.5}$ in 2002.** On-road engines emitted 1,860 tons, or 46% of statewide diesel $PM_{2.5}$ emissions.

- **Off-road, land-based diesel engines generated a significant amount of diesel $PM_{2.5}$ as well,** with 1,726 tons, or 43% of statewide diesel $PM_{2.5}$ emissions.

- **Marine and locomotive engines emitted less than 10% of diesel $PM_{2.5}$.** Marine engines emitted 247 tons, representing 6% of statewide diesel $PM_{2.5}$ emissions. Locomotive engines emitted 142 tons, representing 4% of total diesel $PM_{2.5}$ in Massachusetts.

- **Stationary and area source diesel engines emitted an almost negligible amount of diesel $PM_{2.5}$.** Stationary diesel engines emitted only 32 tons or less than one percent of statewide diesel $PM_{2.5}$ emissions in 2002 whereas area sources emitted 10 tons or less than one percent.

Table 2-3 lists the 2002 $PM_{2.5}$ emissions for the engine groups within each sector, in descending order. Not surprisingly, the largest emitter of diesel $PM_{2.5}$ also happened to be the largest group of diesel engines in the state—those vehicles weighing 26,001 lbs. and over. However, the second highest $PM_{2.5}$ emitter was construction and mining engines, which had the third greatest number of engines (on-road engines weighing under 10,000 lbs. has the second highest number of engines). Similarly, industrial equipment engines, which numbered a little over 10,000 (the seventh greatest number of engines), emitted the third greatest amount of $PM_{2.5}$ in 2002 (289 TPY). A linear relationship clearly does not exist with the number of engines and their annual $PM_{2.5}$ emissions.

Table 2-3. 2002 $PM_{2.5}$ Emissions, By Engine Groups Within Sectors (TPY)

Engine Sector	2002 $PM_{2.5}$ Emissions [a]	Number of Engines
On-Road Engines, 26,001 lbs. and over	1,587	48,625
Construction & Mining Engines	1,113	29,226
Industrial Equipment Engines	289	10,679
C1 and C2 Commercial Marine Engines	222	3,006
Commercial Equipment Engines	198	22,921
Six Off-Road, Land-Based Engine Groups	126	9,138
Line-Haul/Commuter Rail Engines	119	216
On-Road Engines, 19,501-26,000 lbs.	110	13,378
On-Road Engines, <u><</u>10,000 lbs.	107	35,548
On-Road Engines, 10,001-19,500 lbs.	56	23,925
Stationary Source Engines	32	1,081
Small and C1 Recreational Marine Engines	25	7,280
Switchyard Locomotive Engines	23	43
Area Source Engines	10	379

[a] MassDEP estimated the diesel $PM_{2.5}$ emissions for on-road, locomotives, stationary, marine and area source engines. EPA estimated the diesel $PM_{2.5}$ emissions of off-road, land-based engines.

Figure 2-6 shows the percentage contribution of $PM_{2.5}$ emissions for these individual engine groups. On-road engines weighing over 26,000 pounds and construction and mining engines alone comprised over two-thirds of the $PM_{2.5}$ emissions in the state.

Despite the lack of association between the number of engines in a sector and their corresponding diesel $PM_{2.5}$ emissions, it is evident that some engine types pollute more than others. Although engine emissions depend on purpose, the distance traveled by an engine (i.e., on-road engines), the amount of diesel fuel used, and other factors, MassDEP estimated the average per engine $PM_{2.5}$ emissions of engines in 2002 to obtain a sense of per engine emissions by sector. By far, locomotive engines, with average per engine $PM_{2.5}$ emissions of one-half ton, emitted the greatest amount of $PM_{2.5}$ on an average individual engine basis. Table 2-4 and Figure 2-7 show the average $PM_{2.5}$ emissions for each engine within the six sectors analyzed for this inventory.

Table 2-4. Average Per Engine $PM_{2.5}$ Emissions, 2002 (TPY)

Engine Sector	Number of Engines	Annual PM2.5 Emissions	Per Engine PM2.5 Emissions
Locomotive Engines	259	142	0.55
Stationary Source Engines	1,081	32	0.03
Area Source Engines	379	10	0.03
Land-Based, Off-Road Engines	71,964	1,726	0.02
Marine Engines	10,286	247	0.02
On-Road Engines	600,000	1,860	0.003

Table 2-5 and Figure 2-8 present MassDEP's estimate of the average per engine $PM_{2.5}$ emissions of sector engine groups. As discussed earlier, both line-haul/commuter rail and switchyard engines emitted the highest average amounts of diesel $PM_{2.5}$. Average engine emissions from C1 and C2 commercial marine engines were also among the highest of all engine groups. Off-road construction and mining engines, on-road vehicles weighing 26,001 to 60,000 lbs., and stationary diesel engines also represent areas of potential concern for exposure. Exposure to $PM_{2.5}$ may therefore be higher for people working or living around these types of diesel engines.

Table 2-5. Average Per Engine $PM_{2.5}$ Emissions, 2002 (TPY)

Engine Groups	Number of Engines	Annual $PM_{2.5}$ Emissions	Per Engine $PM_{2.5}$ Emissions
Line-Haul/Commuter Rail Engines	216	119	0.55
Switchyard Engines	43	23	0.53
C1 and C2 Commercial Marine Engines	3,006	222	0.07
Construction & Mining Engines	29,226	1,113	0.04
Stationary Source Engines	1,081	32	0.03
Industrial Equipment Engines	10,679	289	0.03
Area Source Engines	379	10	0.03
On-Road Engines, 26,001-lbs. and over	48,625	1,587	0.03
Six Off-Road, Land-Based Engine Groups	9,138	126	0.01
Commercial Equipment Engines	22,921	198	0.01
On-Road Engines, 10,001-19,500 lbs.	23,925	56	0.002
Small and C1 Recreational Marine Engines	7,280	25	0.003
On-Road Engines, $\leq$10,000 lbs.	35,548	107	0.003
On-Road Engines, 19,501-26,000 lbs.	13,378	110	0.008

On the other end of the spectrum, data indicate that on-road vehicles weighing 10,000 lbs. and under, small and C1 marine recreational engines, and on-road vehicles weighing 10,001 to 19,500 lbs. had among the lowest average per engine diesel $PM_{2.5}$ emissions.

As seen in Figure 2-9, diesel sources emitted $PM_{2.5}$ predominantly; coarse PM from diesel combustion sources did not occur in large amounts in Massachusetts in 2002. Based on MassDEP's calculations, $PM_{2.5}$ represented 93% (4,017 tons) of PM_{10} emissions (4,313 tons). The remaining 7% (296 tons) of total PM emissions was coarse PM.

Diesel PM for the area source sector consisted entirely of $PM_{2.5}$. Similarly, on-road engines emitted mostly diesel $PM_{2.5}$, constituting 92% (1,860 tons) of diesel PM_{10} emissions for the sector. Off-road, land-based engines and marine engines were also significant sources of $PM_{2.5}$ (97% and 93%, respectively). The stationary diesel engine sector was the only sector where diesel $PM_{2.5}$ constituted a little over half of total diesel PM_{10} emissions (51%).

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3.0. On-Road Diesel Engines

The on-road diesel engine sector consists of highway vehicles such as trucks, school and transit buses, delivery trucks, 18-wheelers, concrete trucks and many other vehicles. This section discusses state-registered vehicles, vehicles from out-of-state traveling on Massachusetts roadways, school buses, transit buses and waste collection vehicles. These last three groups of vehicles service large populations or travel through highly populated areas emitting diesel $PM_{2.5}$.

3.1. Data Sources

Data for on-road sources come from MassDEP's Enhanced Emissions and Safety Test Program, the U.S. Census, the Massachusetts Department of Revenue, Laidlaw Industries, the Union of Concerned Scientists (UCS), Regional Transit Authorities (RTAs), the Massachusetts Bay Transportation Authority (MBTA), and other sources.

3.2. Number of On-Road Diesel Vehicles

Based on data from the VID and the U.S. Census Bureau, in 2002 there were:

- 121,476 on-road diesel vehicles registered in Massachusetts
- An estimated 481,000 diesel and gas trucks from out of state

Of the 121,476 in-state vehicles, there were:

- 8,497 diesel and gas school buses,
- 4,083 diesel and gas public and private transit buses, and
- An estimated 1,980 diesel waste collection vehicles.

3.2.1. State-Registered On-Road Diesel Vehicles

The Enhanced Emissions and Safety Test Program requires all registered motor vehicles, including all on-road diesel vehicles, to undergo annual vehicle safety inspections. The Vehicle Inspection Database (VID) operated by MassDEP and the Massachusetts Registry of Motor Vehicles (RMV) tracks all the data from these inspections. For the period of January 1 to December 31, 2002, MassDEP identified 121,476 diesel vehicle inspection records in the VID. This number includes approximately 119,000 on-road diesel vehicles and nearly 2,500 off-road vehicles registered with the RMV. Because the off-road vehicle data could not be segregated from the rest of the data without difficulty, the figures and data in this report on diesel on-road vehicles include the 2,476 off-road vehicles. Table 3-1 lists the representative types of vehicles in each weight category.[12]

[12] Although the database is highly accurate and reliable, inspectors at numerous inspection stations throughout the state record the data in the program's database and therefore may underestimate or overestimate certain vehicle data such as vehicle weight.

Table 3-1. Vehicle Weight Classes, By Gross Vehicle Weight Rating (GVWR)

Vehicle Weight Class	Types of Vehicles in Class
$\leq$ 10,000 lbs.	Passenger cars, smaller sports utility vehicles (SUVs)
10,001 to 19,500 lbs.	Delivery vehicles, flatbeds, metro vans, other urban trucks
19,501 lbs. to 26,000 lbs.	Landscaping trucks
26,001 lbs. and over	Dump trucks, concrete trucks, home heating oil trucks

SOURCE: MassDEP, 2006.

As Figure 3-1 shows, the majority of the state's diesel vehicles fell into the 10,001 lbs. and over GVWR weight classes (70%, or more than 85,000 vehicles). According to license plate information in the VID, most of these vehicles were used for commercial purposes. The remaining 35,548 diesel vehicles—almost one third of all on-road diesel vehicles—weighed 10,000 lbs. or less. The largest group of diesel vehicles was the 26,001 lbs. and over GVWR weight class, with 48,625 vehicles. This group also emitted the most diesel $PM_{2.5}$ of all the on-road vehicle classes.

3.2.2. Out-of-State On-Road Vehicles

Specific information on the number of out-of-state trucks is dated. Trucks and buses are required to pay fuel taxes for every mile they travel in other states, regardless of where the vehicle is registered or fueled. In 1995 the Massachusetts Department of Revenue, Division of Motor Fuels, estimated that it issued an estimated 600,000 fuel permits to vehicles traveling in Massachusetts.[13] Subtracting the VID's 119,000 registered in-state vehicles from this number, MassDEP estimates there were some 481,000 out-of-state vehicles traveling on Massachusetts roads in 2002.

Since out-of-state vehicles are not registered in Massachusetts, data are unavailable on the weight class, model year, engine type or fuel used by these vehicles. However, the vehicle miles traveled (VMT) for these vehicles is included in the VMT data provided by the Massachusetts Highway Department (MHD) in the discussion on the PM emissions of on-road diesel vehicles.

3.2.3. School Buses

The Union of Concerned Scientists (UCS) estimated the number of school buses in Massachusetts. UCS identified 8,497 school buses in Massachusetts in 2002,[14] which represented 7% of the state's on-road diesel vehicles. Although this number includes gasoline and diesel-powered school buses, MassDEP's discussions with school bus providers and municipal administrators indicate that most standard large yellow school buses are diesel-powered.

3.2.4. Transit Vehicles

In 2003, MassDEP called each of the state's 14 Regional Transit Authorities (RTAs) and found that they operated 504 standard (i.e., 35-passenger seat) buses, most of which operate on diesel fuel.[15] The number does not include 18-passenger seat shuttles, which frequently operate on gasoline (see

[13]Gus Rankatory, Massachusetts Department of Revenue, Division of Motor Fuels, April 1996.
[14]Patricia Monahan, *Pollution Report Card: Grading America's School Bus Fleets* (Union of Concerned Scientists February 2002).
[15]MassDEP, Bureau of Consumer and Transportation Programs, "Data on Regional Transit Authority (RTA) Bus Fleets," 2004.

Appendix C for a list of Massachusetts RTAs and their vehicle fleets) or those buses operated by the MBTA, which operated over 1,000 transit buses in 2002.[16]

Private bus lines operated 2,579 diesel and gas-powered buses in Massachusetts in 2002.[17] Taken together, these public and private entities operated 4,083 gas and diesel-powered transit buses, or just over 3% of the state's 121,476 on-road diesel vehicles in 2002.

3.2.5. Waste Collection Vehicles

The U.S. Census estimated that there were 1,900 waste collection vehicles in Massachusetts in 2002, excluding municipally-owned garbage trucks. The Census Bureau did not identify the fuel used by the vehicles; however, due to the large size and weight of the vehicles, as well as the power required to operate the auxiliary equipment, MassDEP estimates that the majority of the vehicles used diesel fuel. In addition, MassDEP estimates that there are approximately 20 to 80 municipally owned waste vehicles.

Based on 2004 data collected by MassDEP, 20 of the 160 municipalities that perform curbside waste collection own their garbage trucks. Twenty of the 160 municipalities that perform curbside recycling collection own their recycling trucks (the municipalities in both cases do not necessarily overlap). In general, small municipalities that own their waste collection vehicles have one or two waste trucks while larger communities have 11 or 12 waste trucks. Municipalities are able to use a low number of trucks because the same trucks are used across a number of days in a range of neighborhoods. Using an average of these numbers of vehicles, MassDEP thus estimated that municipalities own approximately 80 waste collection vehicles.

3.3. Growth in On-Road Vehicle Travel

According to the U.S. Department of Energy, for the past 30 years light-duty vehicle travel grew by 2.9%.[18] Several factors are considered in this projection, such as an estimated 1% annual growth in the driving age population, higher fuel prices, and a rising per capita disposable income.

Heavy-duty freight truck travel is expected to grow at a slightly higher rate than light-duty travel. Although truck travel grew by 3% annually over the last several years, it is expected to increase annually by 2.3% from 2004 through 2030. This projected increase will respond to increased product output from the electronics, food, plastics, furniture, and other sectors.

3.4. Vehicle Ownership

The RMV does not provide public information on the owners of diesel vehicles. However, the VID records vehicle plate types, which MassDEP used to identify the number of diesel vehicles owned by state authorities, state agencies, and municipalities. Other sources estimated or tracked vehicle ownership.

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[16]Christine Kirby, MassDEP. Personal interview with the author, Aug. 14 2006.
[17]Tim Davis, Massachusetts Department of Telecommunications and Energy. Telephone conversation with the author, Sept. 4, 2003.
[18]U.S. Department of Energy (DOE), Energy Information Administration, "Annual Energy Outlook 2006 with Projections to 2030 Report," DOE/EIA-0383, 2006. Available on-line at: http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2006).pdf.

3.4.1. Government Vehicles

Based on VID data, state agencies, authorities, and local governments owned 10,807 diesel vehicles. The data do not identify the specific agency, authority or municipality that owns and operates the vehicles or vehicle descriptors other than weight classifications. Based on the data in Figure 3-2, the following conclusions were made:

- **With 8,004 diesel vehicles in the four weight classes, municipalities owned the most diesel vehicles of the three government groups in 2002**. Over 90% of these municipal vehicles were in the 10,001 lbs. and over weight categories.

- **With over 4,700 vehicles, municipalities also owned the most heavy-duty vehicles (over 26,000 lbs. GVWR) of the three groups**.

- **State authorities (e.g., the MBTA and the Massachusetts Water Resources Authority (MWRA)) owned the second largest group of government-owned vehicles**. State authorities owned over 2,000 diesel vehicles, 1,578 of which weighed over 26,000 lbs. State agencies (e.g., MassDEP and the Executive Office of Transportation (EOT)) owned 742 diesel vehicles, 356 of which weighed over 26,000 lbs.

3.4.2. School Buses

UCS, which estimated that there were 8,497 school buses in Massachusetts in 2002, did not identify bus owners. Thus, data on ownership are based on *School Bus Fleet Magazine*'s estimate of 8,200 school buses in Massachusetts in 2000 and Laidlaw International's 2004 data. *School Bus Fleet* estimated that municipalities owned 1,681 (20%) of the school buses in Massachusetts and contracted out the remaining 6,519 school buses (80%) in 2000.

Laidlaw International Inc., a national school bus contractor with operations in Massachusetts, identified approximately 6,300 buses operating in the state. Laidlaw found that only 13% (37) of municipalities owned and operated their own school buses; the other 87% (314) of municipalities, including those participating in regional school districts, privately contracted out their buses. Municipalities owning their fleet operated 555 buses or 9% of the fleet Laidlaw identified. The remaining 314 municipalities contracted with 70 school bus operators to run 5,778 school buses (91%). The list of communities and the number of buses they own or contract out is in Appendix D.

Although the data are from two sources, we can conclude to some extent that municipal ownership of school buses is on the decline and contract operations are on the rise.

3.4.3. Transit Vehicles

The state's 14 RTAs own the large public diesel transit buses, the MBTA owns an additional 1,000 buses, and a large number of private companies own the rest.

3.4.4. Waste Collection Vehicles

As noted earlier, 20 municipalities own their garbage trucks and 20 own their recycling trucks. In general, small municipalities that own their waste collection vehicles have one or two waste trucks while larger communities have 11 or 12 waste trucks.

3.5. Vehicle Purpose and Type

Every five years, the U.S. Census Bureau conducts the Vehicle Inventory and Use Survey (VIUS)[19] to provide statistical data on the nation's on-road truck population. The most recent VIUS, conducted in 2002, was based on Vehicle Identification Number (VIN) registration data obtained from state vehicle registration files.

The Census Bureau mailed a questionnaire to 2,703 owners of private and commercial trucks registered and considered active in Massachusetts as of July 1, 2002. The Census selected this sample of owners from the 1.5 million gas and diesel trucks—including minivans, pickup trucks and sports utility vehicles (SUVs)—registered in Massachusetts. The results of the survey sample were then used to estimate a range of characteristics for the entire Massachusetts fleet, such as body type, model year, cab type, weight class, fuel use, and business purpose.[20] Business purpose was based on 15 specific North American Industrial Classification System (NAICS) business use categories.

The Census presented the data in two formats—one with minivans, pickup trucks and SUVs included and one with them excluded. As shown in Appendix E, MassDEP used the Census data that excluded these three vehicle types, which collectively represented nearly 1.3 million vehicles.[21] The Census also did not track trucks registered to federal, state and local governments, buses, un-powered trailer units, trucks disposed of prior to January 1, 2002, ambulances, farm tractors, and motor homes. The absence of these groups of vehicles explains generally why the total fleet population was only 91,200 gas and diesel powered trucks. Although this number is almost 30,000 vehicles lower than the VID's records of Massachusetts's on-road diesel vehicles, MassDEP has used the data to identify some types and uses of the vehicle fleet:

- **With 20,200 vehicles, the construction industry had the most on-road vehicles in 2002.** Other large fleets included the for-hire transportation and warehousing industry, which operated 12,300 vehicles, and the waste management, landscaping or administrative/support industry, which collectively operated 9,300 vehicles.

- **There were more dump trucks (18,000) than any other body type**. Step or walk-in vans that conduct multiple stops accounted for another 14,600 vehicles, "basic," enclosed vans accounted for 12,700 vehicles, and stake or platform flatbed trucks accounted for about 9,000 vehicles. The VIUS does not define basic, enclosed, or walk-in vans, but walk-in vans may be those used in the express delivery business.

Since the VID does not track the type of vehicles that municipalities use, MassDEP used data (Table 3-2) gathered by TIAX, a consulting firm researching data on California municipal on-road fleets, to approximate the type of vehicles that municipalities in Massachusetts may use. TIAX reported that municipalities in California used dump, utility and pickup trucks the most in 2002. The type of fuel used was unspecified.

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[19]U.S. Census Bureau, "Massachusetts: 2002 Economic Census: Vehicle Inventory and Use Survey, Geographical Area Series," July 2004.

[20]Other VIUS data that are not reflected in Appendix E include: annual VMT, by mileage accrual segments; vehicle primary range of operation, by number of vehicles (e.g., off-the-road, 50 miles or less, 101 to 200 miles, etc.); the number of months vehicles operate; the number of vehicles by total vehicular length; miles per gallon; primary operator classification; equipment type; truck type; and axle arrangement.

[21]According to the Census's 2004 data, minivans comprised 18% (approximately 270,000 vehicles) of the entire truck fleet, pickup trucks, 30% (approximately 450,000 vehicles), and SUVs, 38% (approximately 570,000 vehicles).

Table 3-2. Top 10 Vehicle Types Operated by Public Fleets in California

Vehicle Type	Percent of Vehicle Types
Dump Truck	13%
Utility Truck	12%
Pickup Truck	12%
Van	6%
Cargo Truck	5%
Service Truck	5%
Plow Truck	4%
Sweeper	4%
Other Truck	4%
Plow and Spreader Truck	3%

SOURCE: TIAX, 2003.

3.6. $PM_{2.5}$ Emission Standards and Fuel

3.6.1. $PM_{2.5}$ Emission Standards

To understand the impact of an engine's model year or age, it is important to know the PM emission standards in effect at the time of the engine's manufacture. EPA first regulated $PM_{2.5}$ emissions for on-highway heavy-duty diesel trucks (i.e., engines over 8,500 lbs.) in the 1980s, establishing the first standard for model year 1988 engines. Trucks manufactured before 1988 have no $PM_{2.5}$ controls and represent the dirtiest vehicles on the road. In subsequent years, EPA tightened the standard twice more for model year 1991 and 1994 engines. As Table 3-3 shows, model year 2007 on-road diesel vehicles have the cleanest $PM_{2.5}$ standard thus far (0.01 g/bhp-hr).[22] Final phase-in of the standard is on a percent-of-sales basis: 25% in 2007, 50% in 2008, 75% in 2009, and 100% in 2010.

Federal $PM_{2.5}$ standards for urban buses engines were first promulgated in 1991 and have generally been more stringent (excepting the 2007 standard for truck engines) than standards for heavy-duty diesel truck engines.

Table 3-3. $PM_{2.5}$ Emission Standards for On-Road Diesel Vehicles

	$PM_{2.5}$ Standard (g/bhp-hr)	
Model Year Standard is Effective	Heavy-Duty Diesel Truck Engines	Urban Bus Engines
1988	0.60	--
1991	0.25	0.25
1993	--	0.10
1994	0.10	0.07
1996	--	0.05
2007	0.01	--

SOURCE: DieselNet, no date.

Consumers began to purchase pre-2007 model year vehicles to avoid purchasing model year 2007 vehicles, which were projected to have increased costs due to the required installation of advanced pollution control technology. On-road engine manufacturers sold 26% more heavy-duty trucks in March 2006 than in March 2005. These record sales were also associated with a generally strong economy.[23]

[22]66 FR 5002, Jan. 18, 2001.
[23]"March Truck Sales Smash Record," TTNews.com by Transport Topics (April 2006).

3.6.2. Diesel Fuel

For many years, on-road diesel vehicles operated on diesel fuel with an average in-use sulfur level of 350 ppm. In 2001, EPA required the sulfur level to decrease to 15 ppm in 2006 to facilitate the introduction of model year 2007 vehicles, which require ultra-low levels of sulfur to operate properly. As of October 2006, refiners and importers across the country had to ensure that at least 80 percent of the volume of highway diesel fuel being sold was Ultra Low Sulfur Diesel (ULSD) fuel.[24] Retail outlets may sell either the ULSD fuel alone or in conjunction with the existing 350 ppm-sulfur fuel. The 350-ppm sulfur diesel fuel may only be used in pre-2007 model year heavy-duty vehicles.

By December 2010, the transition to ULSD fuel will be complete as all retail outlets must sell only ULSD fuel by this point. Recent data from fuel suppliers indicate, however, that due to limitations in ensuring the integrity of ULSD fuel and low sulfur diesel (LSD) fuel (500 ppm), most fuel suppliers will sell only ULSD fuel well before the 2010 final deadline.[25] The use of ULSD fuel in on-road vehicles is expected to reduce diesel $PM_{2.5}$ emissions by 5 to 9%.[26]

3.7. Model Year and Gross Vehicle Weight

3.7.1. State-Registered Vehicles

Figure 3-3 shows the VID's data on the model years of the state's on-road diesel vehicles. Although the period of review for this inventory was January 1 to December 31, 2002, a few early MY 2003 vehicles were registered and inspected in 2002 as well. In addition, data are condensed for the 1918 to 1987 model year period before federal or California emission standards were in effect.[27]

According to the VID, the oldest diesel vehicle inspected in 2002 was a model year 1918 vehicle. In addition,

- **The most diesel vehicles (12,891 vehicles) on the road in 2002 were model year 2000**, which were manufactured to meet the 1994 $PM_{2.5}$ emission standard of 0.10 g/bhp-hr, the cleanest standard in effect for the 2002 period of this inventory.

- **Model year vehicles from 1994 to 2003 represented nearly 69% (83,623 vehicles) of on-road diesel vehicles**. This means that the majority of diesel vehicles on the road in 2002 were manufactured to meet the $PM_{2.5}$ standard of 0.10 g/bhp-hr.

- **Nearly 15% of vehicles (18,218 vehicles) were model years 1988 to 1993.** Approximately half of the vehicles in this group were manufactured to meet the 0.25 g/bhp-hr $PM_{2.5}$ emission standard effective for model years 1991 through 1993 vehicles. The other half were required

[24]Clean Diesel Fuel Alliance Information Center, "New Ultra Low Sulfur Diesel fuel and new engines and vehicles with advanced emissions control systems offer significant air quality improvement," no date. Available on-line at: http://www.clean-diesel.org/highway.html.
[25]Steve Levy, Sprague Energy, Clean Construction Workshop (EPA Region 1, Dec. 5, 2006).
[26]U.S. EPA, Office of Transportation and Air Quality, *Technical Highlights: Clean Fuel Options for Heavy-Duty Diesel Trucks and Buses* (EPA 420-F-03-015, June 2003).
[27]New emission standards for model years are effective in vehicles that were manufactured in the preceding calendar year. Thus, while the first federal $PM_{2.5}$ emission standard was effective for model year 1988, dealers began selling model year 1988 vehicles in June of 1987.

to be manufactured to the 0.60 g/bhp-hr $PM_{2.5}$ emission standard effective for model year 1988 through 1990 vehicles.

- **16% of vehicles (19,635 vehicles) were model years 1918 to 1987.** Vehicles in this group were manufactured before there was a $PM_{2.5}$ standard in place. Based on the absence of such a standard, these vehicles emitted the most $PM_{2.5}$ per mile traveled of the diesel vehicles registered in Massachusetts in 2002. Table 3-4 breaks down MY 1918-1987 vehicles into the following groups:

Table 3-4. Number of Pre-1988 Diesel Vehicles, By Decade

Model Years	Number of Diesel Vehicles
1918-1960	70
1961-1970	566
1971-1980	3,494
1981-1987	15,505
Total	*19,635*

SOURCE: MassDEP and Massachusetts RMV, 2006.

A small number of these vehicles are presumed to be antique vehicles or vehicles popular to certain eras (e.g., the 1950s and 1960s) and may not be used extensively.

Figures 3-4, 3-5, 3-6 and 3-7 break down the model year data even further, separating them by general heavy-duty diesel gross vehicle weight rate (GVWR) classes. Note that the vertical scales differ from figure to figure.

In the 10,000 lbs. and under weight class (Figure 3-4), 67% of the 35,548 vehicles were model year 1994 to 2003 and emitted 0.10 g/bhp-hr of $PM_{2.5}$. Another 6% (2,121 vehicles) were model year 1988 through 1990 and emitted 0.60 g/bhp-hr of $PM_{2.5}$. Seven percent (2,602 vehicles) were model year 1991 through 1993 and met the 0.25 g/bhp-hr emission rate. The remaining 6,900 vehicles were manufactured prior to 1988 when no $PM_{2.5}$ emission standard was in place. Passenger cars and smaller SUVs are examples of vehicles in this weight class.

In the 10,001 to 19,500 lbs. weight class (Figure 3-5), the majority (83%) of the 23,925 vehicles were model years 1994 and newer when the $PM_{2.5}$ emission standard became 0.10 g/bhp-hr. The data also show that Massachusetts did not have a significant number (1,060 vehicles) of diesel vehicles in this weight class older than 1988, when the first $PM_{2.5}$ emission standard was promulgated nationally. Delivery vehicles, flatbeds, metro vans, other urban trucks are examples of vehicles in this weight class.

The 19,501 to 26,000 lbs. weight class, which includes landscaping trucks, had the fewest number of diesel vehicles of the four weight classes. As shown in Figure 3-6, 76% of the 13,378 vehicles in this class were model year 1994 and newer. Nearly 6% of the vehicles were model year 1988-1990 vehicles and a little over 7% were 1991-1993 vehicles. The 1918 to 1987 model year group in this weight class had 1,414 vehicles, representing 11% of the weight class. These vehicles were operating with no PM emission standard.

Figure 3-7 illustrates the model years of the 48,625 vehicles in the 26,001 lbs. and over weight class, which includes dump trucks, concrete trucks, and home heating oil trucks. Of these vehicles, 61% (29,645) were model year 1994 or newer. Another 8,709 vehicles, or 18% of this weight class, were model year 1988 to 1993, which means the vehicles were operating on either the 1988 $PM_{2.5}$ standard of 0.60 g/bhp-hr or the 1991 $PM_{2.5}$ standard of 0.25 g/bhp-hr. It should be noted that 10,271 or 21% of the vehicles in this weight class were manufactured prior to 1988 when the first $PM_{2.5}$ standard took effect.

Table 3-5 assimilates the model year and vehicle weight data. Note that:

- **The 26,001 lbs. and over weight class contained the most pre-1988 vehicles (i.e., no $PM_{2.5}$ standard) and the most 1994 through 2003 model year vehicles (i.e., the cleanest $PM_{2.5}$ standard at the time).** Conversely, the 10,001 to 19,500 lbs. weight class had the fewest pre-1988 vehicles.

- **The 19,501 to 26,000 lbs. weight class had the fewest number of vehicles and, of these, the majority was manufactured to the cleanest $PM_{2.5}$ standard in effect in 2002**. The majority of the 10,001-19,500 lbs. vehicles also operated on the 1994 standard, the cleanest $PM_{2.5}$ standard at the time.

Table 3-5. Number of Vehicles, By Model Year and GVWR

	Model Year				
GVWR	Pre-1988	1988-1990	1991-1993	1994-2003	Total
≤10,000 lbs.	6,890	2,121	2,602	23,935	35,548
10,001-19,500 lbs.	1,060	1,391	1,616	19,858	23,925
19,501-26,001 lbs.	1,414	791	988	10,185	13,378
≥26,001 lbs.	10,271	5,098	3,611	29,645	48,625
Total	*19,635*	*9,401*	*8,817*	*83,623*	*121,476*

SOURCE: MassDEP and Massachusetts RMV, 2006.

3.7.2. School Buses

For the 8,497 school buses UCS[28] identified as operating in 2002:

- **19% (1,529 buses) of the school buses were model year 1977 to 1990** and were either not required to meet a $PM_{2.5}$ standard or were manufactured to meet the 1988 $PM_{2.5}$ standard of 0.60 g/bhp-hr.

- **81% (6,899 school buses) were manufactured after 1990**. These school buses were manufactured to meet either the 1991 model year $PM_{2.5}$ standard of 0.25 g/bhp-hr or the model year 1994 $PM_{2.5}$ standard of 0.10 g/bhp-hr.

3.7.3. Transit Vehicles

MassDEP contacted all the state's 14 RTAs in 2003 to collect data on the number, fuel and model year of the state's transit buses. Table 3-6 lists the 504 large RTA transit vehicles by model year and the corresponding $PM_{2.5}$ emission standards for urban buses (i.e., buses weighing over 33,000 lbs.) in effect at the time. The RTAs' smaller transit vehicles, although they may run on diesel, are not regulated under these standards and are therefore not included in this table. Appendix C contains the 2003 data MassDEP collected from the state's RTAs. It includes all sizes of buses and is therefore based on a total of 567 vehicles.

[28]Monahan, 2002.

Table 3-6. Model Years of RTA Vehicles, By $PM_{2.5}$ Emission Standard

Model Years	Number of Vehicles	Urban Bus $PM_{2.5}$ Standard (g/bhp-hr)
Pre-1990	34	NA
1991-1992	99	0.25
1993	35	0.10
1994-1995	164	0.07
1996-2003	172	0.05
Total	*504*	--

SOURCE: MassDEP, 2004.

Of the 504 RTA buses tracked for these data, 34% were model year 1996 to 2003 and met the $PM_{2.5}$ standard for urban vehicles currently in place (0.05 g/bhp-hr). RTA buses manufactured between 1994 and 1995 to meet the 0.07 g/bhp-hr of $PM_{2.5}$ represented 33% of the bus fleet. Twenty percent of the bus fleet was manufactured in 1991 and1992 and met the less stringent 0.25 g/bhp-hr standard. For buses manufactured in 1990 or earlier, 7% of the fleet did not meet any $PM_{2.5}$ standard.

All MBTA buses were manufactured in 1994 or later. Most of the older buses in the MBTA fleet are being replaced.[29]

3.7.4. Waste Collection Vehicles

National data on waste collection vehicles indicate that 41% of the vehicles are ten years old and that the average lifetime is 12 to 14 years. Waste collection vehicles move slowly at an average speed of 10 miles per hour and spend nearly 70% of their time compacting waste loads and idling.[30] Thus, waste collection vehicles are among the highest polluting vehicles on the road and expose workers and neighborhood populations to $PM_{2.5}$.

3.8. PM Emissions of On-Road Diesel Vehicles

MassDEP used MOBILE6.2 to perform two analyses: 1) a sensitivity analysis to identify parameters affecting on-road total PM emissions and 2) a more detailed and precise analysis to quantify the largest sources of on-road exhaust PM emissions.

The first set of analyses examined how parameters such as time of year (season), fuel sulfur content, and fleet age affected PM emissions. It also looked at the breakdown of PM by vehicle class and emission components, differentiating between exhaust and non-exhaust emissions. Non-exhaust sources of PM are brake pads and tire dust. For these model runs, either 2002 or 2005 registration age distributions and diesel sales fractions were used and emissions factors were from EPA's average default speed from MOBILE6.2. Except where noted, the diesel sulfur content was set to 350 ppm (the average sulfur content of on-road diesel fuel prior to EPA's requirement that 80% of diesel fuel sold in the U.S. be ULSD fuel, as of October 2006), and average summer and winter temperatures were used. The results from these analyses, in grams per mile, not tons per day, are presented below:

- **Exhaust PM emissions comprised almost all of the $PM_{2.5}$ for on-road diesel vehicles in 2002.** Based on three groups of diesel vehicle categories, $PM_{2.5}$ emissions were 95% exhaust

[29] Kirby, 2006.
[30] Bill Siuru, "New study makes strong case for natural gas garbage trucks – alternative fuels," (Diesel Progress North American Edition, Nov. 2003).

PM and 5% non-exhaust PM. Diesel on-road vehicle PM_{10} emissions, on the other hand, were 87% exhaust and 13% non-exhaust emissions. See Appendix F for details.

- **Most exhaust-only PM_{10} from on-road vehicles was $PM_{2.5}$.** For exhaust-only emissions, $PM_{2.5}$ constituted 92% of PM_{10}. Coarse PM represented the remaining 8%. For non-exhaust PM emissions, $PM_{2.5}$ constituted only 35% of PM_{10}. For total PM emissions (exhaust and non-exhaust), 70% of PM_{10} was $PM_{2.5}$ or less. (Future inventories thus could address only $PM_{2.5}$ and be assured of quantifying the majority of PM exhaust emissions for on-road engines.) Note these analyses included both gas and diesel emission factors. See Appendix G for details.

- **Seasonal PM effects were minimal.** The winter on-road PM emission factors, which were in grams per mile, were 3% higher than the on-road summer PM emission factors. However, summer VMT was 10% higher than winter VMT, which more than counteracted winter's higher emission factors. Overall, summer PM emissions (tons/day) were 9% higher than winter emissions. Based on these findings, MassDEP decided to calculate annual PM emissions (tons/yr) by adding together summer and winter PM emissions. See Appendix H for details.

- **Fleet turnover will reduce $PM_{2.5}$ by almost 30% from 2002 to 2007.** $PM_{2.5}$ emissions for the entire fleet (gasoline and diesel vehicles) would decrease by 29% over this five-year period, primarily due to fleet turnover when older, dirtier vehicles are retired and replaced by newer, cleaner vehicles. This analysis used a constant 350-ppm sulfur level for the on-road diesel fuel for the analysis years. See Appendix H for details.

- **ULSD fuel will produce limited $PM_{2.5}$ reductions.** As of October 2006, 80% of diesel fuel sold at the pumps was required to be ULSD fuel. MassDEP estimated that the reduction in diesel's sulfur content from 350 ppm to 15 ppm (i.e., sulfur level of ULSD fuel) would reduce diesel PM emissions by 7%, using a 2005 analysis year. EPA cites similar reductions in PM emissions of between 5% and 9%. Note that a 2005 analysis year underestimated the synergistic benefits of using ULSD and PM control technology that are expected to occur in the 2007 model year when tighter PM standards for heavy-duty diesel vehicles take effect. An estimate of the PM reductions from using ULSD fuel and retrofit technologies designed to work with ULSD fuel could be made by re-running the analysis for calendar year 2007. See Appendix I for details.

The second set of on-road analyses focused on the exhaust component of $PM_{2.5}$ emissions and calculated more precise emission rates in tons per day for the different vehicle classes. For this analysis, emission factors were first calculated in grams per mile using MOBILE6 for summer and winter conditions; then they were multiplied by actual Massachusetts VMT totals for 2002 to determine tons per day (TPD). Summer and winter emissions, in tons per day, were then added to obtain total annual PM emissions. Detailed results from this analysis are presented in Appendix J.

The spreadsheets include gasoline vehicles as well as diesel vehicles since gasoline vehicles emit 20% of $PM_{2.5;}$ however, the discussion centers on $PM_{2.5}$ from diesel vehicles only (information on non-diesel sources of $PM_{2.5}$ and PM_{10} can be found in the *Baseline Emission Inventory*).

For these analyses, the following input parameters were used with MOBILE6.2:

- Calendar year 2002
- 2002 Massachusetts-specific registration age distribution

- Default national diesel sales fractions (Massachusetts specific sales fractions were not available for 2002, only 2005)
- Default national VMT fractions by vehicle class based on VMT data of other states (MHD does not collect VMT data by vehicle class)
- Diesel sulfur content of 350 ppm
- Emission factors by freeway and arterial road types
- Emission factors for one mile per hour (mph) increments between 20 and 60 mph

Table 3-7. $PM_{2.5}$ vs. PM_{10} (Exhaust PM), By Vehicle Class

		$PM_{2.5}$					PM_{10}			
Vehicle Class	Description	Avg VMT Fraction	Avg. Emission Factor (g/mi)*	Annual Emissions (TPY)	% of Total	% of Diesel Classes	Avg. Emission Factor (g/mi)	Annual Emissions (TPY)	% of Total	% of Diesel Classes
LDDV	Diesel cars	0.001	0.20	6	0.2%	0.3%	0.21	6	0.2%	0.3%
LDDT	Light trucks <8,500 lbs.	0.002	0.13	14	0.6%	0.7%	0.14	15	0.6%	0.7%
HDDV2B	8,500 – 10,000 lbs.	0.009	0.17	87	3.7%	4.7%	0.18	94	3.7%	4.7%
	Subtotal			*107*	*4.5%*	*5.7%*		*115*	*4.5%*	*5.7%*
HDDV3	10,001 - 14,000 lbs.	0.003	0.15	24	1.0%	1.3%	0.16	26	1.0%	1.3%
HDDV4	14,001 - 16,000 lbs.	0.003	0.15	23	1.0%	1.2%	0.16	25	1.0%	1.2%
HDDV5	16,001 - 19,500 lbs.	0.001	0.13	9	0.4%	0.5%	0.14	10	0.4%	0.5%
	Subtotal			*56*	*2.4%*	*3.0%*		*61*	*2.4%*	*3.0%*
HDDV6	19,501 - 26,000 lbs.	0.007	0.29	110	4.7%	5.9%	0.31	119	4.7%	5.9%
	Subtotal			*110*	*4.7%*	*5.9%*		*119*	*4.7%*	*5.9%*
HDDV7	26,001 - 33,000 lbs.	0.010	0.32	172	7.4%	9.3%	0.33	186	7.4%	9.3%
HDDV8A	33,001 - 60,000 lbs.	0.012	0.39	269	11.6%	14.5%	0.42	291	11.5%	14.4%
HDDV8B	>60,000 lbs.	0.042	0.42	1037	44.5%	55.8%	0.46	1122	44.3%	55.8%
HDDBT	Urban/transit bus	0.001	0.83	44	1.9%	2.4%	0.90	47	1.9%	2.4%
HDDBS	School bus	0.001	0.77	65	2.8%	3.5%	0.84	71	2.8%	3.5%
	Subtotal			*1,587*	*68.2%*	*85.5%*		*1,717*	*67.9%*	*85.4%*
Total Diesel		*0.090*		*1,860*	*79.9%*	*100.0%*		*2,012*	*79.5%*	*100.0%*
LDGV	Gasoline cars	0.440	0.006	160	6.9%	-	0.007	170	6.7%	-
LDGT12	Light trucks <6,000 lbs.	0.314	0.007	127	5.5%	-	0.007	135	5.3%	-
LDGT34	Light trucks <8,500 lbs.	0.118	0.008	53	2.3%	-	0.008	58	2.3%	-
HDGV	Trucks > 8,500 lbs.	0.034	0.062	125	5.4%	-	0.075	151	5.9%	-
MC	Motorcycles	0.004	0.017	4	0.2%	-	0.024	6	0.2%	-
Total Gas		*0.910*		*469*	*20.1%*			*519*	*20.5%*	
Total Fleet		**1.000**		**2,329**	**100%**			**2,531**	**100%**	

* These emission factors do not calculate PM emissions from idling.

SOURCE: MassDEP, 2006.

Based on this analysis, MassDEP drew the following conclusions, which are shown in Table 3-7 and Figure 3-8:

➢ **The heaviest diesel vehicles emitted the most $PM_{2.5}$ in 2002.** Vehicles weighing more than 60,000 lbs. GVWR (i.e., class HDDV8B), such as 18-wheelers, were the largest contributors to on-road diesel $PM_{2.5}$ emissions with nearly 56% of on-road diesel emissions. The next largest contributors were vehicles weighing 33,001 to 60,000 lbs. (e.g., dump trucks), with over 14% of diesel $PM_{2.5}$ emissions, and those vehicles weighing 26,001 to 33,000 lbs. (e.g., large trucks), with 9% of on-road diesel $PM_{2.5}$ emissions.

- **Light-duty and medium-duty diesel vehicles emitted the least $PM_{2.5}$ in 2002.** Vehicles in the 10,000 lbs. and under vehicle classes (i.e., diesel cars and light-duty trucks) accounted for 6% of diesel $PM_{2.5}$ emissions, whereas the 10,001 to 19,500 lbs. vehicle classes (i.e., HDDV3, HDDV4, and HDDV5) only accounted for 3% of on-road diesel $PM_{2.5}$ emissions.

- **Transit and school buses were the dirtiest vehicles on the road but their overall $PM_{2.5}$ emissions were small when compared to other vehicle weight classes.** The transit and school bus categories had the highest average PM emission factors (0.83 and 0.77 g/mile, respectively), but their low VMT made them relatively small contributors to total PM**.**

The contribution of out-of-state vehicles to $PM_{2.5}$ emissions is unknown since the $PM_{2.5}$ estimates did not distinguish emissions from out-of-state vehicles from those of in-state vehicles.

With 1,860 tons, $PM_{2.5}$ emissions constituted 92% of total PM for the on-road engine sector in 2002. Coarse PM, with 152 tons, represented only 8% of total PM emissions in the state. Figure 3-9 shows the breakdown across the 12 vehicle classes. Vehicles weighing over 60,000 lbs. emitted the most $PM_{2.5}$—and the most coarse PM.

3.9. References for On-Road Diesel Engines

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4.0. Off-Road, Land-Based Diesel Engines

According to EPA, an off-road engine is one that is installed on: 1) self-propelled equipment; 2) equipment that is propelled while performing its function; or, 3) equipment that is portable or transportable. The diesel $PM_{2.5}$ inventory presents data on nine equipment groups in the off-road land-based diesel engine sector.[31] Examples of the equipment in each group are only for diesel-fueled equipment:

- **Agricultural Equipment**: Diesel agricultural tractors, combines, balers, tillers, and sprayers.
- **Airport Ground Support Equipment**: Diesel baggage tractors, fuel carts, and aircraft tow tractors.
- **Commercial Equipment**: Diesel air and gas compressors, generators, pressure washers, pumps, and welders.
- **Commercial Lawn and Garden Equipment**: Diesel commercial chippers/stump grinders, turf equipment, front mowers, lawn and garden tractors, leaf blowers/vacuums, and snow blowers.
- **Construction/Mining Equipment**: Diesel boring and drill rigs, concrete and mortar mixers, cranes, crawler tractors, bulldozers, crushing and processing equipment, dumpers, excavators, graders, off-highway trucks, paving equipment, rough terrain forklifts, rubber tire loaders, scrapers, skid steer equipment, tampers, loaders, backhoes, and trenchers.
- **Industrial Equipment**: Diesel forklifts, refrigeration, sweepers/scrubbers, and tractors.
- **Logging Equipment**: Diesel fellers, skidders and shredders with engines greater than six horsepower (hp).
- **Railroad Equipment**: Diesel ballast cleaners, ballast regulators, and tie replacers. (Locomotive line-haul and switchyard engines are addressed in Section 6.0, *Diesel Locomotive Engines*.)
- **Recreational Equipment**: Diesel specialty vehicle carts (the only diesel recreational equipment covered).

4.1. Data Sources

The primary sources of data on the number and type of off-road mobile engine equipment in Massachusetts are EPA and Power Systems Research (PSR), a data management company that tracks

[31]The *Baseline Emission Inventory* estimates emissions for ten off-road equipment groups. This diesel $PM_{2.5}$ inventory discusses data on the same ten groups, except the discussion on pleasure craft (i.e., marine recreational vessels) is in Section 5.0, *Marine Diesel Engines*.

the sales and populations of all types of engines sold in the United States.[32] In addition, MassDEP's VID tracks some data on off-road vehicles registered in Massachusetts. However, since VID data are limited to those off-road vehicles that occasionally operate on a public roadway, data on the type and number of off-road vehicles are not comprehensive. The U.S. Census, private business entities, and the California Air Resources Board also provided data.

4.2. Number of Off-Road, Land-Based Diesel Engines

EPA estimated that there were 71,964 diesel-fueled off-road, land-based engines in Massachusetts in 2002, using its own data and data from PSR. In general, EPA used national engine and population sales data obtained by PSR. However, PSR maintained proprietary rights over its methodology to allocate equipment populations from the national level to the county level to generate state off-road mobile equipment totals. As a result, EPA used 2002 data from the U.S. Census Bureau on population, housing, and income, when available, to allocate the national PSR equipment populations to the county level. EPA also used Census data on business activities and geographic data relating to a county's specific physical characteristics.[33]

Table 4-1 presents the number of diesel engines estimated by EPA for this sector in 2002. Figure 4-1 presents the data graphically by percentage. With 29,226 engines, the construction and mining equipment category contained the most diesel engines in this sector in 2002 (42% of all off-road, land-based diesel engines). Commercial equipment followed, with 22,921 engines (32% of land-based engines). The next two largest categories of equipment were industrial equipment (10,679 engines) and commercial lawn and garden equipment (6,800 engines). Together, these last two categories represented 24% of the engines in the sector. The other five categories (i.e., agriculture, airport, logging, railroad, and recreational engines) represented 2,338 engines (3%). See Appendix K for EPA's list of the types of engines within each off-road, land-based diesel engine category.

Table 4-1. Number of Off-Road, Land-Based Diesel Engines

Diesel Equipment Category	Number
Construction and Mining Equipment	29,226
Commercial Equipment	22,921
Industrial Equipment	10,679
Lawn and Garden Equipment	6,800
Agricultural Equipment	1,039
Recreational Equipment	809
Airport Equipment	334
Logging Equipment	130
Railroad Equipment	26
Total	*71,964*

SOURCE: EPA, 2006.

[32]The Secretary of State's Corporation Division tracks equipment registered by Uniform Commercial Code (UCC); however, data are based on industry codes and are only accessible with prior knowledge of the names of owners.
[33]U. S. EPA, Office of Transportation and Air Quality, *Geographic Allocation of Nonroad Engine Population Data to the State and County Level* (NR-014d, EPA 420-R05-021, December 2005).

4.3. Growth in the Number of Off-Road, Land-Based Diesel Engines

The U.S. Census Bureau tracks the number of business establishments categorized under the NAICS as construction and mining. This gives some perspective on the scope of some industries that most likely use off-road engines in Massachusetts. The 2002 Economic Census found that Massachusetts had 17,100 individual establishments[34] in the construction industry and 105 in the mining industry.[35] As shown in Table 4-2, these data indicate that each of these industries experienced substantial growth between 1997 and 2002.

Table 4-2. Growth in Construction and Mining Industries in Massachusetts

NAICS Industries	Number of Establishments In 1997[36]	Number of Establishments In 2002	Percent Change
Construction	14,959	17,100	14.3%
Mining	72	105	44.7%

SOURCE: U.S. Census, no date.

In addition to the increased number of construction and mining establishments, there has been a general increase in the number of off-road construction equipment engines. The research firm, MacKay & Co., conducted a nationwide survey in 2003 of diesel and gasoline off-road construction equipment.[37] MacKay & Co. identified 1,429,000 equipment units in operation in 2003, representing a 10% increase over 1999 when the company conducted its first survey.

MacKay & Co. found that over 20 of 28 categories of off-road equipment experienced growth due to increased production to meet the demand for new rental equipment and the increasing diversity of equipment attachments designed to expand the use of the primary equipment (e.g., skid-steer loaders). While several categories of equipment experienced growth, other categories decreased due to rapidly changing technology, making the existing type of equipment dated or obsolete. A change in the economy—from the economic growth period of 1999 to the economic decline of 2003—also contributed to a drop in the number of certain types of off-road equipment from one survey period to the next.

CARB also identified several groups of engines that experienced growth from 1999 to 2003, as shown in Table 4-3.

[34]According to the U.S. Census Bureau, establishments are defined as a relatively permanent office or other place of business where the usual business activities related to construction are conducted. An establishment does not represent each project or construction site. This definition covers all establishments that were in business at any time during the year, including full-year and part-year operations.
[35]U.S. Census Bureau, *Massachusetts 2002: 2002 Economic Census, Mining, Geographic Area Series,* “Table 1: Employment Statistics for Establishments by State, 2002” (ECO2-21-A-MA, May 2005).
[36]U.S. Census Bureau, “2002 Economic Census Comparative Statistics for Massachusetts Summary Statistics by 1997 NAICS,” no date. Available on-line at: http://www.census.gov/econ/census02/data/comparative/MACS.HTM.
[37]*Construction Equipment*, “America’s Fleet Remains Strong,” August 2003.

Table 4-3. Growth in Off-Road Construction Equipment, Nationwide

Equipment	Number of Vehicles In 2003	Percent Growth in Vehicle Numbers
Asphalt Pavers	15,971	8%
Backhoe-Loaders	254,712	6%
Boring/Drilling Equipment	11,648	36%
Concrete Pavers	4,665	4%
Excavators, Crawlers	156,535	41%
Graders	48,276	6%
Off-Highway Haulers	7,264	24%
Rough-Terrain Forklifts	30,538	11%
Skid-Steer Loaders	281,726	22%
Trenchers, Rubber-Tired	63,896	14%

SOURCE: CARB, no date.

4.4. Annual Usage of Equipment

In addition to the surveys mentioned above, CARB and TIAX, a consulting company, conducted surveys of the annual usage of construction equipment in California. TIAX surveyed publicly owned on-road and off-road equipment for CARB in 2003.[38] CARB surveyed publicly and privately-owned construction/mining equipment in 2005.[39] Table 4-4 shows the average annual use of some typical pieces of equipment used in the construction industry based on these data.

Table 4-4. Average Annual Usage of Construction Equipment in California

Equipment	Average Usage (Hours/Year)	Source
Boring/Drilling Equipment	811	MacKay
Bulldozers	1,589	CARB, TIAX
Cranes	1,252	MacKay
Crawler Tractors	1,013	CARB, TIAX
Excavators	1,396	CARB, TIAX
Graders	929	MacKay
Off-Highway Haulers	1,958	MacKay
Off-Highway Tractors	1,091	CARB, TIAX
Pavers	821	MacKay
Paving Equipment	829	MacKay
Rollers	695	MacKay
Rough-Terrain Forklifts	1,123	MacKay
Rubber Tired Loaders	957	CARB, TIAX
Rubber-Tired Trenchers	618	MacKay
Scrapers	1,092	CARB, TIAX
Skid-Steer Loaders	834	MacKay
Surfacing Equipment	446	CARB, TIAX
Wheel Loaders	942	CARB, TIAX

SOURCE: CARB, no date.

According to CARB and an expert in the off-road construction equipment field,[40] off-road engines are used predominantly when they are new. Once they reach a certain age, operating costs or maintenance costs dictate that the engines are used only when absolutely necessary.

[38] TIAX, 2003.
[39] California Air Resources Board (CARB), "Off-Road Equipment Rule – Inventory Updates," no date.
[40] Marty Lassen, Johnson Matthey. E-mail to the author, Nov. 6, 2006.

CARB also developed data on the average annual use of selected pieces of industrial equipment (Table 4-5) that MassDEP used to approximate equipment usage in Massachusetts.

Table 4-5. Average Annual Use of Industrial Equipment in California

Equipment	Average Usage (Hours/Year)
Aerial Lifts	384
Forklifts	1,800
Other General Industrial Equipment	1,425
Other Material Handling Equipment	1,318

SOURCE: CARB, no date.

Of the types of off-road, land-based equipment, the following engines in Table 4-6 are those most used by municipal fleets in California:

Table 4-6. Top 10 Equipment Types Used in California, Public Fleets

Equipment Category	Number of Engines	Percent of Equipment Types
Loader	1,035	19%
Grader	676	12%
Forklift	518	9%
Backhoe Loader	467	8%
Road Sign	342	6%
Mower	309	6%
Track-Type Tractor	247	4%
Generator	191	3%
Tractor	183	3%
Roller	169	3%

SOURCE: TIAX, 2003.

4.5. Ownership

Massachusetts regulations[41] require that a registration plate be affixed to an off-road vehicle if the vehicle will be used on a public roadway. These off-road vehicles, although not subject to periodic emissions tests, must undergo an annual safety inspection. The Massachusetts VID tracks the data from the safety inspections and provides general categories of ownership of these vehicles.

Figure 4-2 shows the ownership of the plates associated with the inspected vehicles. The data reflect 2,700 off-road vehicle inspections that occurred from January 1 to December 31, 2002. Municipalities own over 54% or 1,481 of the off-road vehicles that are registered to operate on a public way. Private commercial companies own and operate almost 21% of the vehicles that use a commercial license plate. Any vehicle that is involved in the conduct of business can obtain a commercial plate. State agencies own 10% (270 vehicles) and authorities (e.g., the Massachusetts Water Resources Authority or MWRA) own 3% (78 vehicles).

The VID does not capture the true number of vehicles traveling on a public roadway because many off-road vehicles (e.g., excavators) are transported by another vehicle such as a flatbed truck and thus never need to travel on a public roadway. In addition, for some vehicle plate types, plate applicants can obtain a single plate that can be legally attached to numerous vehicles for a period of time. For example, businesses that own a fleet of ten or more motor vehicles, trailers, mobile construction cranes

[41]M.G.L. c90, §§9 34.

or combinations of these, can obtain an "owner/contractor" plate and use it for more than one vehicle. These plates are similar to the "dealer" plates used by automobile dealerships when dealers allow customers to test-drive several vehicles with the same license plate.

The RMV does not require applicants to provide data on the off-road equipment or vehicle that will display a plate. However, some plate applicants voluntarily provide information on their equipment's make, engine class and gross vehicle weight.

In addition, limited data are available for nationwide patterns of ownership for certain pieces of off-road, land-based diesel engine equipment. MacKay and Co. found that, nationwide, 10 to 40% of certain kinds of off-road construction equipment are rented and 20 to 37% are leased, making tracking of individual pieces of equipment difficult (Table 4-7).

Table 4-7. Ownership of Construction/Mining Equipment Diesel Engines, Nationwide

Equipment	Number of Vehicles	Percent [a]			
		Rented	Leased	Purchased New	Purchased Used
Asphalt Pavers	15,971	10	-	70	-
Backhoe-Loaders	254,712	38	-------------45----------------		17
Boring/Drill Equipment	11,648	-	19	48	-
Concrete Pavers	4,665	18	-	-	-
Excavators, Crawlers	156,535	16	------------50+---------------		20
Graders	48,276	14	-	49	16
Off-Highway Haulers	7,264	-	37	------------85-------------	
Rough-Terrain Forklifts	30,537	40	25	18	19
Skid-Steer Loaders	281,726	33	-	-	-
Trenchers, Rubber-Tired	63,896	-	-	50	28

[a] In almost all cases, the percentages in the last four columns do not add up to 100% because *Construction Equipment* magazine omitted pieces of information for some types of equipment. For instances when the numbers surpass 100%, the magazine did not provide an explanation.

SOURCE: MacKay & Co., 2003.

4.6. $PM_{2.5}$ Emission Standards and Fuel

PM emissions in the off-road, land-based diesel engine sector were largely uncontrolled until the 1990s. This means that vehicles manufactured before this period emit much more diesel $PM_{2.5}$ than a vehicle manufactured today.

4.6.1. $PM_{2.5}$ Emission Standards

Although EPA set emission standards for on-road vehicles in the early 1970s, no emission standards for off-road, land-based engines were established until the Clean Air Act Amendments of 1990 directed EPA to evaluate and regulate the emissions from these engines. As a result, in 1994 EPA developed Tier 1 emission standards for engines with 50 or more horsepower to be phased in from 1996 to 2000.[42]

Four years later, EPA established Tier 1 standards for engines under 50 horsepower and increasingly more stringent Tier 2 and Tier 3 standards for NOx, HC, and PM for other off-road diesel

[42]U.S. EPA, "Regulatory Announcement: New Emission Standards for Nonroad Diesel Engines" (EPA420-F-98-034, August 1998). Available on-line at: http://www.epa.gov/nonroad-diesel/frm1998/f98034.htm.

engines (Table 4-8).[43] Tier 2 standards were effective for MY 2001 to 2006 engines, and Tier 3 standards are effective for MY 2006 to 2008 engines with 50 to 750 hp. However, Tier 3 PM standards were never adopted.[44, 45] In 2004, EPA established Tier 4 emission standards[46] for off-road engines, to be phased in from 2008 to 2015.[47] The standards, which will reduce PM by over 90%, will be achieved with the use of exhaust after-treatment technologies.

Table 4-8. Tier 1, 2 and 4 $PM_{2.5}$ Emission Standards for Off-Road Diesel Engines [a]

Engine Power	Tier	Effective Model Year	PM (g/bhp-hr)
<11 hp	1	2000	0.75
	2	2005	0.60
	4	2008	0.30
≥11 hp to <25 hp	1	2000	0.60
	2	2005	0.60
	4	2008	0.30
≥25 hp to <50 hp	1	1999	0.60
	2	2004	0.45
	4	2008	0.22
≥50 hp to <75 hp	1	-	-
	2	2004	0.30
	4	2013	0.02
≥75 hp to <100 hp	1	-	-
	2	2004	0.30
	4	2012	0.02
≥100 hp to <175 hp	1	-	-
(e.g., crawlers/bulldozers)	2	2003	0.22
	4	2012	0.02
≥175 hp to <300 hp	1	1996	0.40
(e.g., tractors)	2	2003	0.15
	4	2011	0.02
≥300 hp to <600 hp	1	1996	0.40
(e.g., hydraulic excavators)	2	2001	0.15
	4	2011	0.02
≥600 hp to <750 hp	1	1996	0.40
(e.g. wheel loaders)	2	2002	0.15
	4	2011	0.02
≥750 hp	1	2000	0.40
	2	2006	0.15
	4	2011	0.08
Generator sets	4	2015	0.02
All engines except generator sets	4	2015	0.03

[a] The standards do not cover marine vessels <50 hp, locomotives and underground mining equipment. EPA regulates these marine vessels and locomotives separately. The Mine Safety and Health Administration (MSHA) regulates diesel emissions and air quality in mines.

SOURCE: EPA, 1997.

[43] 63 FR 56968, Oct. 23, 1998.
[44] The 1998 federal rule explained that EPA did not implement the Tier 3 standards for $PM_{2.5}$ because the agency preferred to discuss the standards at a 2001 feasibility review.
[45] Greg Orehowsky, EPA. Telephone conversation with the author, May 23, 2007.
[46] According to DieselNet (dieselnet.com), the Tier 4 regulation does not require closed crankcase ventilation for off-road engines. However, for engines with open crankcases, compliance with Tier 4 emission standards will be determined by adding crankcase emissions to exhaust emissions.
[47] 69 FR 38958, June 29, 2004.

4.6.2. Diesel Fuel

Diesel fuel for off-road, land-based engines will be substantially cleaner in the next four years under a 2004 EPA rule.[48] Starting in June 2007, the sulfur level of off-road diesel fuel decreased to 500 ppm, an 83% drop from the previous 3,000 ppm-sulfur level. EPA required the use of low sulfur diesel (LSD) fuel to help achieve the Tier 4 emission standards for off-road, land-based engines, which will require after-treatment technology that may be contaminated by high sulfur levels in diesel fuels. Under the same rule, in June 2010, the level will decrease to 15 ppm, the current sulfur level of on-road ultra low sulfur diesel (ULSD) fuel.

EPA has estimated that on-road diesel engines emit 5 to 9% less $PM_{2.5}$ when using ULSD fuel than fuel with a 500-ppm sulfur level.[49] For off-road vehicles using ULSD fuel, the decrease in diesel $PM_{2.5}$ emissions will most likely be far larger due to the large drop in the sulfur content.

Table 4-9 shows EPA's estimate of diesel fuel usage by diesel equipment category. The data show that:

- **The largest engine category, the construction and mining engine category, used the most diesel fuel--84 million gallons—of the off-road engine categories in 2002**. The next largest users of diesel fuel were industrial equipment engines (over 23 million gallons) and commercial equipment engines (over 11 million gallons).

- **On an average per engine basis, logging engines consumed the most fuel (8,057 gallons per year) of the off-road engine categories.** Airport equipment also consumed a high average amount of fuel (4,200 gallons per year) on a per engine basis. This high average consumption level was due to the small number of engines in each of these groups (130 logging engines and 334 airport equipment engines).

With over 71,000 engines consuming 156 million gallons of fuel each year, the sulfur reductions in LSD and ULSD fuel will result in significant $PM_{2.5}$ reductions.

Table 4-9. Fuel Usage of Off-Road, Land-Based Diesel Equipment

Diesel Equipment Category	Number of Engines	Diesel Fuel Consumption (Gallons/Year)	Average Per Equipment (Gallons/Year)
Agricultural Equipment	1,039	1,782,938	1,716
Airport Equipment	334	1,403,345	4,202
Commercial Equipment	22,921	11,879,687	518
Construction and Mining Equipment	29,226	84,404,479	2,888
Industrial Equipment	10,679	23,484,499	2,199
Lawn and Garden Equipment (Commercial)	6,800	4,038,150	594
Logging Equipment	130	1,047,441	8,057
Railroad Equipment	26	45,210	1,739
Recreational Equipment	809	251,861	311
Total	71,964	156,675,220	--

SOURCE: EPA, 2006; MassDEP, 2006.

[48] 69 FR 38958, June 29, 2004.

[49] U.S. EPA, Office of Transportation and Air Quality, *Technical Highlights: Clean Fuel Options for Heavy-Duty Diesel Trucks and Buses* (EPA 420-F-03-015, June 2003).

4.7. Average Age and Useful Life

Industry surveyor MacKay & Co. also provided national data on the average age, useful life, average age traded, and annual use of off-road construction equipment (Table 4-10). Based on a small selection of construction equipment, off-road, land-based engines have shorter average useful lives than on-road diesel engines. On-road diesel engines can last as long as 30 years whereas the off-road construction equipment listed in Table 4-10 have useful lives ranging from 10 to 22 years (CARB also found similar useful life ranges). The primary lifespan of the vehicles—the period during which the equipment operates at optimal efficiency—is even shorter, with a range of five years for boring equipment to 12 years for graders.

Table 4-10. Average Current Age, Primary Lifespan, and Other Data on Off-Road Construction Equipment (Years)

Equipment	Average Current Age	Primary Lifespan	Average Age Traded	Useful Life
Asphalt Pavers	8	10	--	18
Backhoe-Loaders	6	10	--	18
Boring/Drill Equipment	4	5	--	10
Concrete Pavers	7	11	10	17
Excavators	6	9	7	17
Graders	8	12	14	22
Off-Highway Haulers	6	7	7	13
Rough-Terrain Forklifts	8	11	9	16
Rubber Tired Trenchers	7	10	--	13
Skid-Steer Loaders	5	8	9	13
Wheel Loaders	9	8	6	21

SOURCE: MacKay & Co., 2006.

Most current off-road equipment engines are relatively young; the average current age ranges from four years for boring equipment to nine years for wheel loaders. If the oldest average current age is almost nine years—making the equipment a model year 1998—then many vehicles (i.e., those having from 175 to 750 hp) were manufactured to meet at least Tier 1 emission standards for $PM_{2.5}$. Engine owners and operators also appear to trade engines with some frequency. The range of the average age traded for the engines in Table 4-10 was six to 14 years.

Furthermore, shorter life spans mean that as more vehicles are retired, more users will purchase or lease vehicles that meet the Tier 4 standards, which take effect between 2008 and 2015, depending on the engine's horsepower. EPA recently estimated that the country's entire inventory of off-road diesel vehicles—approximately 1.8 million vehicles—should be upgraded by 2030 based on the average expected vehicle lifetime. However, this date may be delayed by consumers "pre-buying" engines in advance of a new model year standard where advanced technology requirements generally increase the costs of vehicles. This type of activity took place in the on-road sector in advance of the model year 2007 emission standards.[50]

CARB also estimated the useful life of off-road industrial equipment (Table 4-11), finding a useful range of 12 to 16 years.

[50]A.C.T. Research Co. reported a 25.2% spike in new orders for 2006 heavy-duty diesel trucks in *Fleet Owner* (January 6, 2006 issue).

Table 4-11. Useful Life Estimates of Off-Road Industrial Equipment in California

Equipment	Useful Life (Years)
Aerial Lifts	16
Forklifts (25 to >300 hp)	12
Other General Industrial Equipment (25 to >300 hp)	16
Other Material Handling Equipment	16

SOURCE: CARB, 2007.

4.8. PM Emissions of Off-Road, Land-Based Diesel Engines

MassDEP used EPA's Office of Transportation and Air Quality (OTAQ) national NONROAD2005 Mobile Emissions Model (Version 2005a, February 2006) to determine the PM emissions of diesel engines in this sector.[51] The NONROAD model estimates emissions from over 300 engine types of off-road equipment based on national data from PSR (the information management contractor), state, and local data inputs. Emissions are based on a 2002 equipment population distributed by age, application, power, and fuel type.

According to MassDEP's *Baseline Emission Inventory*, the NONROAD model uses data from PSR to estimate average activity in hours per year by equipment type and emission factors per work unit. The emission factors were time-weighted to account for age distribution. EPA's MOBILE6 highway model provided emission factor deterioration rates for the NONROAD emission factors.

Although the model primarily uses an engine's activity level to estimate engine emissions, on occasion EPA had to use population-oriented indicators, or a combination of both, as a surrogate for engine activity. This information was supplemented with state and industry-specific data. The model assumes that each piece of equipment in a category operates the same amount of time.

Population and business activity data for 2002 came from the U.S. Census Bureau. The U.S. Census, the National Oceanographic and Atmospheric Administration and the U.S. Geological Survey provided geographic data relating to a county's location or physical traits. For additional information on estimating emissions for this sector, see EPA's *Geographic Allocation of Nonroad Engine Population Data to the State and County Level.*[52]

Figure 4-3 shows the diesel $PM_{2.5}$ emissions of the nine off-road equipment groups in this sector in 2002, which collectively emitted 1,726 TPY of diesel $PM_{2.5}$. In addition,

- **With 65% (1,113 TPY) of the sector's $PM_{2.5}$ emissions, the construction and mining engine group emitted the most $PM_{2.5}$ of all off-road land-based engines in 2002**. In fact, construction and mining equipment engines emitted nearly six times more $PM_{2.5}$ than industrial equipment (289 TPY) and commercial equipment engines (198 TPY), the next two highest emitting groups.
- **The other six equipment groups collectively emitted 126 tons of diesel $PM_{2.5}$**. This represented only 7% of the diesel $PM_{2.5}$ emissions for this sector.

[51]MassDEP has used a version of EPA's NONROAD model for every required emissions inventory year (1990, 1993, 1996, 1999, and 2002) and for 2007 projections of statewide emissions in preparation for the development of State Implementation Plans (SIPs). MassDEP has used the model to estimate emissions for a typical summer and winter day for ozone and annual emissions for SO_2 and PM.
[52]EPA, 2005.

Appendix K provides the PM emissions of specific types of equipment within each category.

Figure 4-4 shows the number of tons of $PM_{2.5}$ and coarse PM. $PM_{2.5}$ represented 97% of diesel PM_{10} in 2002. Coarse PM represented only 3% of total PM. This means that the overwhelming majority of the PM released by off-road, land–based diesel engines is the PM that presents the most health risk to the population.

4.9. References for Off-Road, Land-Based Engines

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U.S. EPA. "Regulatory Announcement: New Emission Standards for Nonroad Diesel Engines." EPA420-F-98-034. August 1998. Available on-line at: http://www.epa.gov/nonroad-diesel/frm1998/f98034.htm.

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5.0. Marine Diesel Engines

The marine diesel engine sector consists of a wide range of marine vessels from tugboats and commercial fishing vessels to whale watch vessels, commuter boats, and pleasure vessels. This section discusses the types and number of engines, their model years and PM emissions, and several other characteristics.

5.1. Data Sources

As shown in Table 5-1, several agencies track data on marine vessels. The Massachusetts Division of Marine Fisheries (DMF) records the vessels of commercial fishermen that are required to obtain a permit from DMF to off-load their fish catch at Massachusetts' docks. The Massachusetts Office of Law Enforcement (OLE) requires all boats that operate on public waterways in Massachusetts and which are powered by a motor[53] to register their vessels with the agency, with some exceptions.[54] Boats owners that register their boats in another state are allowed to visit Massachusetts for up to 60 consecutive days without obtaining a Massachusetts registration and title. Vessels that are registered or "documented" with the United States Coast Guard (USCG), such as commuter boats and ferries, are also exempt from OLE's registration requirements.

USCG requires vessels of five net[55] tons or more—generally vessels more than 25 feet in length—that are used in fishing activities, passenger service or coast-wide trade to register with the USCG.[56] In addition, all vessels carrying more than six passengers must be "certificated" by the USCG for compliance with marine vessel regulations.[57]

In most cases, data sources segregated diesel-fueled vessels from non-diesel fueled vessels. In other cases, all tracked vessels—such as the commerce-carrying vessels tracked by the U.S. Army Corps of Engineers—were grouped together, regardless of fuel use. The PM emissions of most commercial marine vessels, some of which may have used non-diesel fuel, were based on the Corps data.

[53]Registration is required even if the motor is not the primary means of propulsion, according to OLE's website, <http://www.mass.gov/dfwele/dle/boatregfaq.htm>.
[54]www.mass.gov/dfwele/dle/boatregfaq.htm.
[55]Net tonnage is a measure of a vessel's volume, according to the USCG.
[56]U.S. Coast Guard, National Vessel Documentation Center, "Frequently Asked Questions," November 2005. Available on-line at: http://www.uscg.mil/hq/g-m/vdoc/faq/htm.
[57]Capt. Mary Landry, USCG, First Coast Guard District. Correspondence with the author, July 10, 2006.

Table 5-1. Data Sources for Number of Marine Diesel Vessels

Source	Data Year	Marine Vessel Data Covered
Corps of Engineers	2002	▪ Number of trips made by domestic commerce-carrying vessels, including passenger vessels, dry cargo vessels, tankers and towboats/tugboats traveling in MA ▪ Fuel type not specified ▪ Trips segregated by draft size (18 feet and under; over 18 feet)
Corps of Engineers	2004	▪ Ownership, home port, passenger capacity, build and rebuild years, draft size, horsepower and other data on domestic commercial vessels, including ferries and other passenger vessels, operating in MA ▪ Fuel type not specified
DMF	2006	▪ Number of permits issued to people for in-state and out-of-state commercial fishing vessels using MA waterways and off-loading fish catch at Massachusetts ports ▪ Fuel type not specified ▪ Ownership, vessel length, permit type and home port data ▪ Data adjusted to 2002 levels
Northeast States for Coordinated Air Use Management (NESCAUM)	2005	▪ Number of diesel-only ferries/excursion vessels, tugboats, dredging and government vessels operating in Boston Harbor ▪ Ownership, vessel length and fuel consumption data ▪ Data adjusted to 2002 levels
OLE	2002	▪ Number of diesel-only vessels registered in MA, including livery, commercial pleasure, government, enforcement, small commercial fishing (<5 net tons), and pleasure craft ▪ Ownership, vessel length, use, type, horsepower, model year, registration number, storage town and other data
USCG	2006	▪ Number of "documented" commercial diesel vessels, including vessels carrying over six passengers, commercial fishing vessels $\geq$5 tons, school ships, research vessels, freight, industrial and towing vessels ▪ Fuel type not specified for several thousand vessels ▪ Data adjusted to 2002 levels

MassDEP also obtained data from harbormasters, harbor commissions, a dredging company, and the Massachusetts Governor's Seaport Advisory Council.

5.2. EPA Marine Engine Categories

EPA regulates the emission standards of marine vessel engines[58] according to several broad categories, as shown in Table 5-2. These are broad categories and specific types of vessels within the categories may have a C1 or C2 commercial engine (e.g., police vessels may have C1 or C2 engines, depending on the displacement of the vessel). C1 diesel marine engines are most similar to land-based off-road diesel engines in terms of the power and size of their engines. C2 diesel marine engines are most like locomotive engines.

[58] *Marine engine* means an engine that is installed or intended to be installed on a marine vessel. This definition does not include portable auxiliary engines for which the fueling, cooling and exhaust systems are not integral parts of the vessel (64 FR 73334, Dec. 29, 1999).

Table 5-2. EPA Marine Engine Categories

Category	Rated Power	Displacement (Liters/Cylinder)	Examples of Vessels
Small	<37 kW	Any	Some sailboats, recreational pleasure boats
C1 Recreational	≥37 kW	≥0.9 to 5.0	Pleasure boats, some charter fishing, and generator sets
C1 Commercial	≥37 kW	<5	Fishing vessels, workboats, dredges, police boats, and other general small harbor craft
C2	≥37 kW	≥5 to <30	Tugboats, supply vessels, ferries, and auxiliary power engines used by ocean-going vessels
C3	≥37 kW	≥30	Container ships, oil tankers, bulk carriers, and cruise ships

SOURCE: EPA, 2004.

Category 1 and 2 vessels—those vessels with displacement of less than 30 liters per cylinder—operate on diesel or distillate fuel oil.[59, 60] Distillate fuel oil includes diesel and other types of fuel, including No. 1 and No. 2 fuel oil.

Category 3 engines generally use residual oil (RO), a heavier, non-diesel fuel, or marine diesel oil (MDO), a heavy distillate fuel with small amounts of residual fuel.[61, 62] Foreign-flagged vessels are C3 vessels and burn RO in their main propulsion engines and either RO, MDO or marine gas oil (MGO) in their auxiliary engines.[63] Since C3 engines burn non-diesel fuels, these vessels are not addressed in this inventory.

The data sources used in this inventory do not specifically cite whether an engine is a C1, C2 or C3. MassDEP therefore categorized the engine sources by the type of marine vessel (i.e., a tugboat is a C2 engine). In some cases, such as the small and C1 recreational vessels, MassDEP was unable to segregate the engine types and thus grouped them together.

5.3. Number of Marine Diesel Vessels

Table 5-3 shows that nearly 10,300 marine vessels operated on diesel fuel in Massachusetts in 2002. Figure 5-1 illustrates the percent contribution of each vessel category to the marine diesel engine sector. Over 70% (7,280) of the engines were small and C1 recreational diesel vessels. C1 commercial diesel vessels formed the other significant part (24%) of the total, with approximately 2,500 vessels. C2 engines were 5% of the vessel total.

[59]State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials (STAPPA/ALAPCO), "Danger in Motion: It's Time to Clean Up Trains and Boats" (February 2006).
[60]Jean Marie Revelt, EPS, Conference on Marine Vessels and Air Quality (EPA, San Francisco, CA, February 2001).
[61]Karen Walsh Peterson, New Bedford Harbor Development Commission. E-mail to the author, Mar. 15, 2006.
[62]ICF Consulting, *Current Methodologies and Best Practices in Preparing Port Emission Inventories: Final Report* (Jan. 5, 2006).
[63]Ibid.

Table 5-3. Total Number of Marine Diesel Vessels, By EPA Engine Category

Vessel Category	Number of Vessels	Data Source
Small and C1 Recreational	7,280	USCG, 2006; OLE, 2006
C1 Commercial	2,480	OLE, 2006; USCG, 2006; DMF, 2006; Corps, 2002; NESCAUM, 2006
C2	526	USCG, 2006
Total	*10,286*	---

As is explained in subsequent sections, these data most likely underestimate the number of diesel dredging, recreational, and governmental vessels operating in Massachusetts in 2002.

5.3.1. Small and C1 Recreational Marine Diesel Vessels

Of the 138,000 recreational boats in use in Massachusetts, 7,280 were fueled by diesel in 2002 (Table 5-4).[64] Private citizens owned the bulk of the engines; only a few (14) were livery vessels that were rented out for private use (e.g., fishing excursions). MassDEP estimated that these engines were either small or C1 recreational engines. Of these, over 1,900 vessels weighed less than five tons. The remaining 5,332 vessels were the larger recreational diesel vessels weighing five or more tons and owned by Massachusetts citizens.

MassDEP adjusted the USCG number to 2002 from a 2006 data total of 6,323 vessels, taking into account a 3.5% annual growth rate in recreational vessels.[65] Even so, the total number of 7,280 vessels was nearly 4% higher than EPA's geographic-based estimate of 7,027 recreational vessels, on which MassDEP based its emissions estimate for these vessels.[66]

Table 5-4. Number of Small and C1 Recreational Marine Diesel Vessels

Recreational Vessel Type	Number of Vessels	Data Source
Vessels <5 tons	1,948	OLE, 2006
Vessels $\geq$5 tons	5,332	USCG, 2006
Total	*7,280*	--

5.3.2. C1 Commercial Marine Diesel Vessels

Ranging in length from 20 feet to several hundred feet, C1 commercial marine diesel vessels include large and small fishing vessels, dredges, workboats, and excursion vessels such as whale watches. Some of these vessels may run on non-diesel fuels. Generally, smaller vessels use diesel, gasoline or MDO. Passenger boats carrying from 30 to 80 passengers generally run on diesel fuel.[67] Larger vessels, such as the Boston Harbor Express and Boston Harbor commuter ferries, may run on diesel or RO. Virtually all dredging vessels operate on diesel fuel.[68]

The list below reflects the marine engines that DMF, OLE, and USCG track that are believed to be C1 commercial engines. The Corps does not specifically track dredging vessels but a Corps

[64]OLE, 2006; USCG, 2006.
[65]Revelt, 2001.
[66]Capt. Laurel Carlson, Coast Guard Auxiliary. Personal interview with the author, June 29, 2006.
[67]Ibid.
[68]John Mikutowicz, AGM Marine Contractors, Inc. Telephone conversation with the author, Aug. 3, 2006.

representative estimated that approximately 30 dredging projects occur each year.[69] A private dredging contractor further estimated that generally one vessel operates on each project.[70]

- **Commercial fishing vessels:** These vessels consist of: 1) smaller commercial fishing vessels weighing under five tons registered with OLE (e.g., a lobster boat); 2) large fishing vessels weighing five or more net tons registered with USCG; and 3) vessels that are home ported in another state but which off-load their fish catch at a Massachusetts port.

- **Commercial pleasure vessels:** Vessels that are run by commercial operators for private use, such as guide boats. These are distinguished from larger excursion, sightseeing vessels, such as whale watches, that must undergo certification by the USCG.

- **Dredging vessels:** Dredging-related vessels, such as dipper dredges**,** clamshell dredges, cutterhead pipeline dredges, and self-propelled hopper dredges.

- **Educational vessels:** Research vessels, such as those used by the Wood's Hole Oceanographic Institute in Falmouth, Massachusetts to conduct investigations of marine life, or school ships, such as those used by Tabor Academy in Marion, Massachusetts to educate students about marine topics.

- **Government vessels:** Coast Guard and U.S. Navy vessels as well as fire, police and harbor enforcement vessels.

Table 5-5 lists the number of diesel vessels in the C1 commercial engine category. MassDEP adjusted the 2006 USCG and DMF data to 2002 using an annual growth rate for C1 engines of 1%.[71] MassDEP also adjusted the data the Northeast States for Coordinated Air Use Management (NESCAUM) collected on government vessels operating in Boston Harbor in 2005.[72] Using an annual 1% growth rate,[73] MassDEP determined that 44 diesel-powered government vessels operated in the harbor in 2002. This number was added to the 40 diesel-fueled government vessels OLE identified as operating in other areas of the state in 2002. Since annual growth rates are unavailable for educational vessels and the number of vessels was very small, MassDEP did not adjust this number for the year 2002.

Of the approximately 2,500 vessels in the C1 commercial engine category, over 900 vessels were known to operate on diesel fuel. MassDEP apportioned the remaining 1,554 vessels to diesel fuel based on an extrapolation of USCG data.[74]

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[69]Marie Farese and Karen Adams, U.S. Army Corps of Engineers. E-mail to the author, Aug. 1, 2006.
[70]Mikutowicz, 2006.
[71]Revelt, 2001.
[72]Northeast States for Coordinated Air Use Management (NESCAUM), *Final Report: Scoping Study to Evaluate the Emissions of Harbor Craft Operating in Boston Harbor and Potential Control Options*, April 2006.
[73]Revelt, 2001.
[74]These numbers were apportioned to diesel fuel by first determining the ratio of known diesel-fueled engines to the total number of vessels with a known fuel type, and then applying that ratio to the number of vessels using an unspecified fuel.

Table 5-5. Number of C1 Commercial Diesel Marine Vessels in Massachusetts

Vessel Type	Number of Vessels	Number Apportioned To Diesel	Total	Data Source
Commercial Fishing, <5 tons	370	-	370	OLE, 2006
Commercial Fishing, ≥5 tons	386	1,207	1,593	USCG, 2006
Commercial Fishing (Out-of-State)	-	347	347	DMF, 2006
Subtotal	*756*	*1,554*	*2,310*	--
Commercial Pleasure	48	-	48	OLE, 2006
Dredging	30	-	30	Corps, 2002
Educational	8		8	USCG, 2006
Governmental	84	-	84	OLE, 2006; NESCAUM, 2006 [a]
Total	*926*	*1,554*	*2,480*	--

[a] NESCAUM categorizes most of the police boats using Boston Harbor as C2 engines. For the purpose of grouping vessel categories together, MassDEP assigned these vessels to the C1 engine category. EPA generally categorizes government vessels as C1 engines.

Figure 5-2 shows that:

- **Diesel commercial fishing vessels weighing five or more tons were by far the largest number of C1 commercial diesel marine vessels in 2002, with 64% of the engine category**. Within the three categories of commercial fishing vessels, vessels weighing five tons or more represented 69% of the group (see Table 5-5).

- **Government vessels and commercial pleasure vessels were, respectively, only 3% and 2% of the C1 commercial vessels in the state in 2002**. Dredging and educational vessels were one percent or less of the commercial vessels.

5.3.3. C2 Marine Diesel Vessels

Data on the number of C2 diesel engines are derived from USCG and NESCAUM. USCG tracked data on freight, industrial, passenger, and towing vessels. The freight vessel engines could possibly be C3 engines. Included in these data are the C2 vessels that NESCAUM identified as using Boston Harbor in 2005. Adjusted to 2002 levels, based on a 1% annual growth rate,[75] there were an estimated 34 ferries and excursion vessels and 15 tugboats, pushboats, and towboats in Boston Harbor at that time.

C2 diesel engines in 2002 consisted of the following types of vessels:

- **Freight ships**: U.S.-flagged vessels transporting commerce to U.S. ports.

- **Industrial vessels**: U.S.-flagged vessels associated with construction activities, such as cable-laying vessels.

- **Passenger vessels**: Vessels that carry over six passengers. These include commuter boats, ferries, amphibious boats (i.e., "Duck" boats), excursion vessels, and dinner cruises. Some of these may be C1 commercial vessels.

- **Towing vessels**: Towboats, pushboats or tugboats tow or push barges within and outside of a port. Towboats are more commonly used for ocean-going vessels whereas pushboats are

[75] Revelt, 2001.

used for vessels along riverways.[76] Vessels may engage in unit tow operations where they haul bulk materials or conduct bunkering moves to fuel ocean-going vessels. Vessels may also engage in line-haul operations to tow a barge through a channel or to a port.[77]

Table 5-6 shows that there were over 500 C2 marine diesel engines in Massachusetts. USCG provided the data on the number of diesel vessels. MassDEP apportioned the remaining number of engines to diesel fuel based on a ratio of fuel usage from the known diesel engines cited by USCG. Figure 5-3 shows that 76% of these engines were passenger vessels in 2002. Diesel towing vessels comprised the other significant portion (20%) of the C2 marine engine fleet.

Table 5-6. C2 Marine Diesel Engines in Massachusetts

Vessel Type	Number of Diesel Vessels	Number Apportioned To Diesel	Total Diesel Vessels
Freight	5	2	7
Industrial	1	17	18
Passenger	207	189	396
Towing	7	98	105
Total	*220*	*306*	*526*

SOURCE: USCG, 2006; MassDEP, 2006.

5.4. Growth in the Number of Marine Diesel Engines

Table 5-7 displays EPA's projected national annual growth rate of marine diesel engines. Recreational marine diesel vessels, with an annual growth rate of 3.5%, are expected to increase by over 250 vessels each year in Massachusetts. C1 Commercial vessels are expected to increase by 24 vessels and C2 vessels may increase by five vessels, assuming an average growth rate of 1%.

Table 5-7. National Annual Growth Rate of Marine Engines, By EPA Category

Marine Engine Category	Average Annual Growth Rate	Vessel Example
C1 Recreational	3.5%	Pleasure boats
C1 Commercial	0.9%	Yachts, cruisers
C2	1.0%	Tugboats, ferries
C3[78]	1.0%	Oil Tankers, cruise ships

SOURCE: Revelt, 2001.

Conversations with several harbormasters in Massachusetts support the projected growth in large vessel calls to their ports. The City of Salem, for example, recently constructed a permanent wharf to operate a ferry service to Boston.[79] The New Bedford Harbor Development Commission had projected increased bulk cargo activity in the harbor in 2006 due to recent dredging work.[80]

[76]ICF, 2006.
[77]NESCAUM, 2006.
[78]The United States' contribution to the world's ocean-borne commerce is projected to grow at an estimated annual rate of 3.3%. Domestic and foreign vessel operators are expected to build larger vessels to accommodate the projected increase in cargo. However, large international vessels operate on RO.
[79]Frank Taormina, City of Salem Planning Department. E-mail correspondence with the author, Mar. 29, 2006.
[80]Peterson, 2006.

5.5. Ownership

OLE, DMF and the Corps of Engineers provided data on the owners of marine diesel vessels (Appendices L, M, and N, respectively) in 2002. Ownership data are for fishing vessels weighing less than five tons, ferries, livery, government and recreational vessels.

5.6. Home Ports

DMF collects data on commercial fishing permits issued to people in and outside of Massachusetts. Although these data include the home ports of fishing vessels, the true number of vessels at each port is difficult to ascertain because many fishermen receive more than one fishing permit and the data do not reveal whether more than one vessel is used for the different permits. In addition, most commercial fishermen do not own boats and fish from off-shore. Only about one-third of fishermen are full-time commercial fishermen.[81]

For these reasons, the number of DMF-issued fishing permits in Table 5-8 is higher than the number of fishing vessels listed in Table 5-5. Still, this table gives a broad sense of the possible distribution of fishing vessels in waterways throughout the state. The DMF data were adjusted from 2006 to 2002 for this inventory using a 1% growth adjustment factor.[82]

The most fishing permits were issued for Gloucester, New Bedford and Chatham harbors. Other data (not shown in this table) suggest that New Bedford Harbor had the most USCG-documented vessels weighing five or more tons and Gloucester Harbor had the most fishing vessels weighing less than five tons.[83] USCG-certified fishing vessels most likely operated on diesel fuel whereas vessels registered with DMF operated on diesel fuel or gasoline.

Table 5-8. Home Ports of Permits Issued for Fishing Vessels in Massachusetts

Waterway	Number of Permits Issued	Waterway	Number of Permits Issued
Gloucester Harbor	395	Falmouth Harbor	76
New Bedford Harbor	280	Marblehead Harbor	63
Chatham Harbor	231	Dartmouth Harbor	61
Boston Harbor	140	Barnstable Harbor	60
Plymouth Harbor	134	Wellfleet Harbor	59
Fairhaven Harbor	130	Rockport Harbor	56
Provincetown Harbor	129	Edgartown Harbor	51
Newburyport Harbor	124	Cohasset Harbor	49
Westport Harbor	113	Manchester Harbor	43
Nantucket Harbor	106	Sesuit Harbor	42
Sandwich Basin	100	Menemsha Creek	40
Green Harbor	99	Salem Harbor	40
Scituate Harbor	95	Salisbury Harbor	37
		Total	*2,818*

SOURCE: DMF, 2006.

[81]DMF, 2006.
[82]Revelt, 2001.
[83]DMF, 2006.

In addition, the U.S. Army Corps of Engineers collects data on the number of trips made by foreign and domestic marine vessels transporting commerce. With a few exceptions, all Massachusetts ports and waterways must report the number of one-way upbound[84] or inbound trips made by tugs, towboats, dry cargo vessels, tankers and passenger vessels. Harbors do not need to report trips made by:

- Department of Defense vessels carrying military cargo, although they must report trips made by commercial vessels carrying cargo for military agencies;
- General ferries carrying coal and petroleum products loaded from shore facilities directly into fuel bunkers or cargo vessels;
- Sightseeing/excursion, governmental, recreational and fishing vessels; and,
- Tugboats used to assist larger vessels, although many harbors volunteered data despite the Corps's relaxation of this reporting requirement.[85]

Waterways must also submit data on the number of vessel trips made by draft size. Draft is the amount of water that is displaced by a vessel and is not related to a vessel's length. Waterways reported data on draft size using the Corps of Engineers' draft parameters of over 18 feet and 18 feet and under. However, EPA, in its guidance on estimating marine vessel emissions, established the draft parameters as 18 feet and over and less than 18 feet. As a result, MassDEP adjusted a portion of the Corps data to correspond with EPA's parameters.

Massachusetts waterways did not report the *number* of commercial vessels making trips to their areas nor did they report data by vessel fuel usage to the Corps. Many waterways also did not segregate data on domestic vessel trips from foreign vessel trips.

Table 5-9 shows that in 2002, domestic self-propelled commercial vessels made nearly 126,000 inbound or upbound trips in the 21 Massachusetts harbors and waterways reporting data to the Corps.

- **Edgartown Harbor reported the most trips with almost 63,000 inbound commercial vessel trips, or 172 trips per day on a year-round basis.** Numerous daily trips of the Chappaquiddick On Time ferry and the Steamship Authority ferry trips undoubtedly contributed to this elevated number.
- **With 19,413 inbound trips, the Main Waterfront of Boston[86] reported the next highest number of vessel trips.** Vineyard Haven, with 14,588 trips, and Hyannis Harbor, with 13,229 trips, also reported significant numbers of domestic vessel trips.
- **With 123,953 trips or 98% of total trips, domestic and "unspecified" passenger/dry cargo trips represented the largest category of commercial trips.** Tanker trips represented barely one percent of total commercial trips.

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[84]Upbound vessels move in an upstream direction.
[85]U.S. Army Corps of Engineers, Institute for Water Resources, "Waterborne Commerce of the United States, Calendar Year 2002, Part 1-Waterways and Harbors, Atlantic Coast" (IWR-WCUS-02-1, 2002).
[86]The Corps of Engineers separated the Port of Boston into numerous waterways within a 47-square mile area, including Boston Harbor's Main Waterfront, Chelsea River, Mystic River, Weymouth Fore River, Town River, Hingham Harbor, Malden River, Neponset River, Reserved Channel, Weymouth Back River, Winthrop Harbor and Island End River. Table 5-9 divides the vessel trips by Boston's Main Waterfront, Chelsea River, Mystic River, Weymouth Fore River, and Town River.

- **Tow and tug trips represented 1% of total trips**. New Bedford/Fairhaven Harbor, Fall River Harbor, Vineyard Haven and Cape Cod Canal ran the most towboats and tugboats.

Table 5-9. Number of Commercial Domestic Trips, All Draft Sizes (One-Way)

	Domestic			Unspecified			
Waterway*	Pass/ Dry Cargo	Tanker	Tow/ Tug	Pass/ Dry Cargo	Tanker	Tow/ Tug	Total
Boston, Main Waterfront	19,315	-	98	-	-	-	19,413
Cape Cod Canal	-	27	202	-	-	-	229
Chelsea River	-	2	103	-	-	-	105
Cuttyhunk Harbor (<u><</u>8')	-	-	-	-	-	8	8
Edgartown Harbor (<u><</u>4')	-	-	-	62,818	-	-	62,818
Fall River Harbor	51	-	233	-	-	-	284
Falmouth Harbor	-	-	-	785	-	-	785
Gloucester (<u><</u>23')	-	-	-	1	291	-	292
Green Harbor	-	-	-	-	-	-	-
Hyannis Harbor (<u><</u>11')	-	-	-	13,229	-	-	13,229
Island End River				44	-	-	44
Mystic River	-	3	34	-	-	-	37
Nantucket, Refuge Harbor (<u><</u>14')	-	-	-	10,853	11	38	10,902
New Bedford/Fairhaven	732	-	672	-	-	-	1,404
Newburyport	-	-	-	-	-	-	-
Plymouth Harbor (<u><</u>29')	-	-	-	17	-	-	17
Provincetown Harbor (<u><</u>7')	-	-	-	-	-	1	1
Salem Harbor	-	-	2	-	-	-	2
Town River	-	4	12	-	-	-	16
Vineyard Haven (<u><</u>12')	-	-	-	14,381	-	207	14,588
Westport Harbor (<u><</u>12')	-	-	-	3	-	-	3
Weymouth Back River (<u><</u>8')	-	-	-	1,724	-	-	1,724
Weymouth Fore River	-	1	17	-	-	-	18
Total	*20,098*	*37*	*1,373*	*103,855*	*302*	*254*	*125,919*

* No trips were reported for the following rivers: Andrews, Annisquam, Essex, Malden, Menemsha Creek, Neponset, or Taunton, or the following harbors: Beverly, Chatham, Cohasset, Dorchester Bay, Duxbury, Green, Hingham, Lynn, Manchester, Marblehead, Mattapoisett, Rockport, Scituate, Wareham, Wellfleet, and Winthrop.

SOURCE: Corps of Engineers, 2002.

Table 5-10 shows the number of domestic vessel trips, by draft size, in the waterways reporting these data. [87]

Of the two draft parameters, vessels with drafts under 18 feet comprised 99% of inbound trips. Vessels with drafts 18 feet and over made up the remaining 1% of total trips (1,274 trips). Generally, vessels with larger draft sizes have auxiliary diesel generator systems to power refrigeration, electricity and other services.[88] These generators produce dockside emissions. Based on these data, it is assumed that all or part of these 1,274 vessels idled their engines at ports in 2002, emitting $PM_{2.5}$. However, these vessels may have used either RO or distillate fuel and thus their $PM_{2.5}$ emissions may not have been diesel $PM_{2.5}$ emissions.

[87] Although not shown in the tables in this inventory, Corps data showed that domestic vessel trips represented 97% of inbound trips of commercial vessels. Foreign-flagged vessel trips were just 3% of the total.
[88] ICF, 2006.

Table 5-10. Number of Commercial Domestic Vessel Trips, By Draft Size (One-Way)

	Number of Vessel Trips		
Waterway	≥18 feet	<18 feet	Total
Boston, Main Waterfront	1,000	18,413	19,413
Cape Cod Canal	41	188	229
Chelsea River	25	80	105
Cuttyhunk Harbor	-	8	8
Edgartown Harbor	-	62,818	62,818
Fall River Harbor	84	200	284
Falmouth Harbor	-	785	785
Gloucester Harbor	92	200	292
Hyannis Harbor	-	13,229	13,229
Island End River	-	44	44
Mystic River	13	24	37
Nantucket, Harbor of Refuge	-	10,902	10,902
New Bedford/ Fairhaven Harbor	0	1,404	1,404
Plymouth Harbor	8	9	17
Provincetown Harbor	-	1	1
Salem Harbor	0	2	2
Town River	7	9	16
Vineyard Haven	-	14,588	14,588
Westport River	-	3	3
Weymouth Fore River	4	14	18
Weymouth Back River	-	1,724	1,724
Total	*1,274*	*124,645*	*125,919*

SOURCE: Corps of Engineers, 2002.

5.7. Annual Usage

Marine vessels run propulsion engines when they maneuver in and out of port and operate along waterways. Many marine vessels also run their propulsion engines (main boilers) and auxiliary diesel generators to power utilities such as refrigeration, electricity, heating/cooling and ventilation while in port (boilers rarely shut down in port because it takes a long time to prepare them for operation). Table 5-11 shows the average annual operating hours of these engine types in the Port of Los Angeles, which MassDEP used as a broad gauge to approximate the operating hours of engines in Massachusetts.

Table 5-11. Average Engine Horsepower and Annual Operation Hours, Port of Los Angeles

Vessel Category	Propulsion Engine: Engine Power (kW)	Propulsion Engine: Annual Operating Hours	Propulsion Engine: Percent Category 2 Engines	Auxiliary Engine: Engine Power (kW)	Auxiliary Engine: Annual Operating Hours
Assist Tug	1,532	1,043	44%	82	1,207
Commercial Fishing	204	1,647	0%	51	1,932
Crew Boat	284	606	0%	72	700
Dredge	1,531	372	0%	214	372
Dredge Tender	450	158	0%	19	136
Excursion	250	1,971	0%	41	2,199
Ferry	803	1,672	0%	25	1,616
Government	237	413	0%	176	156
Line Haul Towboat	3,357	654	80%	82	859
Tugboat (Unit Tow)	903	654	25%	56	859
Work Boat	266	345	0%	23	618

SOURCE: ICF, 2006.

Excursion vessels, ferries, and commercial fishing vessels—the three vessel categories that run their propulsion engines the longest—also ran their auxiliary engines the longest. The data in Table 5-11 provide an indication of how long these engines operate while in port and their potentially significant emissions.

5.8. $PM_{2.5}$ Emission Standards and Fuel

5.8.1. $PM_{2.5}$ Emission Standards

From 1998 to 2003, EPA established national PM standards for small,[89] C1 recreational,[90] C1 commercial,[91] and C2[92] marine vessels (Table 5-12). In the past, small marine diesel engines (i.e., those under 37 kW) were regulated as off-road, land-based engines. However, engines in this size category are now covered by marine emission standards.

[89] 63 FR 56968, Oct. 23, 1998.
[90] 67 FR 68241, Nov. 8, 2002; 68 FR 9746, Feb. 28, 2003.
[91] 64 FR 73300, Dec. 29, 1999; 68 FR 9746, Feb. 28, 2003.
[92] 64 FR 73300, Dec. 29, 1999; 68 FR 9746, Feb. 28, 2003.

Table 5-12. Tier 1 and Tier 2 PM Emission Standards for Diesel Marine Engines

Category	Displacement (Liter/Cylinder)	Power (kW)	Tier	Model Year	PM (g/kW-hr)
Small	-	<8 kW	1	2000	1.0
			2	2005	0.8
	-	8≤ kW <19	1	2000	0.8
			2	2005	0.8
	-	19≤ kW <37	1	1999	0.8
			2	2004	0.6
C1	D <0.9			2007	0.4
Recreational [a]	0.9≤ D <1.2	≥37 kW	2	2006	0.3
	1.2≤ D <2.5			2006	0.2
	2.5≤ D <5.0			2009	0.2
C1	D <0.9			2005	0.4
Commercial	0.9≤ D <1.2	≥37 kW	2	2004	0.3
	1.2≤ D <2.5			2004	0.2
	2.5≤ D <5.0			2007	0.2
C2	5≤ D <15	-			0.27
	15≤ D <20	<3300kW			0.5
	15≤ D <20	≥3300kW	2	2007	0.5
	20≤ D <30	-			0.5

[a] Tier 1 emission standards for C1, C2, and C3 vessels were only for NO_x and are thus not included in this table.

SOURCE: U.S. EPA, 2004. The emission standards for engines less than 37 kW can be found at 40 CFR Part 89 and, for all other engines, at 40 CFR Part 94.

In March 2007, EPA proposed new Tier 3 emission standards for C1 and C2 engines.[93, 94] The standards would apply as early as 2009 to the smallest marine diesel engines, 2012 for most other marine engines used in commercial (excluding ocean-going vessels), recreational, and auxiliary vessels, and would reduce $PM_{2.5}$ by up to 90%. Tier 4 standards would also be established for C2 engines above 800 hp (over 600 kW) and recreational marine diesel engines above 2,000 hp (over 1,400 kW) and would take effect in 2014, two years after ULSD marine fuel (i.e., sulfur level of 15 ppm) is to be phased in.

The emission standards would be similar to those established for the on-road and off-road, land-based diesel engine sectors. Without such controls, EPA estimates that locomotives and marine diesel engines will contribute about 65% of mobile source $PM_{2.5}$ emissions by 2030.[95]

5.8.2. Diesel Fuel

EPA required new sulfur limits for marine diesel fuel in a June 2004 rulemaking.[96] The sulfur levels in marine diesel fuel decreased from 3,000 ppm to 500 ppm in June 2007 and are required to decrease to 15 ppm in June 2012. The new sulfur limits apply to Nos. 1 and 2 distillate fuels, but do not pertain to diesel fuel heavier than No. 2 distillate used in C2 and C3 marine engines, blends of distillate heavier than No. 2 used with residual fuel, or residual fuel. With significant drops in sulfur levels, diesel $PM_{2.5}$ emissions are expected to decrease as well.

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[93]U.S. EPA, "Regulatory Announcement: EPA Proposal for More Stringent Emissions Standards for Locomotives and Marine Compression-Ignition Engines" (EPA420-F-07-015, March 2007). Available on-line at: http://www.epa.gov/otaq/regs/nonroad/420f07015.htm.
[94]EPA is also proposing to change the definition of C1 and C2 engines to a 7 liters per cylinder cut-off. EPA, 2007.
[95]U.S. EPA, "Regulatory Announcement: EPA Proposal for More Stringent Emissions Standards for Locomotives and Marine Compression-Ignition Engines" (EPA420-F-07-015, March 2007).
[96]69 FR 38958, June 29, 2004.

5.9. Average Age and Useful Life

Most marine diesel vessels in Massachusetts were not manufactured with PM emission controls in place in 2002, as Table 5-13 illustrates. Across vessel types,

- **Nearly 85% of the 1,900 marine vessels in Massachusetts for which there were age data were manufactured or rebuilt without any PM emission controls**. These vessels were manufactured before 1999, the year PM emission standards first became effective for certain vessels (i.e., small engines with between 19 and 37 kW).

- **Only 15% of the surveyed engines were built from 1999 to 2004**. Of this group, only "small" engines with less than 19 kW were required to meet a PM standard; PM emission standards for C1 recreational, C1 commercial and C2 were not required until 2006, 2004 and 2007, respectively. This means that almost all marine engines manufactured before 2002 did not meet PM emission standards.

Data in Table 5-13 are based on 2002 OLE data and 2004 Corps data adjusted to 2002 levels, based on a 1% growth rate.[97]

Table 5-13. Build Years of Some Diesel Vessels in Massachusetts

Vessel Type	Pre-1999	1999-2004	Total
Small & C1 Recreational	1,130	211	1,341
C1 Commercial	321	51	372
C2	189	32	221
Total	1,640	294	1,934

SOURCE: OLE, 2006; Corps of Engineers, 2004.

Depending on its size, the useful life of a marine vessel ranges from 10 to 30 years, according to EPA. C2 and C3 engines have the longest life spans (Table 5-14). Often an engine's lifetime is extended further by an engine rebuild. Many boats have at least one engine rebuild during their operating life, depending on general vessel operation and maintenance.

Table 5-14. Average Life and Age Range of Marine Engines, By EPA Category

Marine Engine Category	Average Useful Life (Years)	Age Range (Years)	Vessel Examples
C1 Recreational	15	10-20	Pleasure boats
C1 Commercial	13	10-20	Yachts, cruisers
C2	23	20-30+	Tugboats, ferries

SOURCE: Revelt, 2001.

With such long useful lives, the turnover rate for marine vessels is low. This observation and the fact that 85% of 1,900 tracked marine vessel engines were manufactured with no emission standards indicate that many marine diesel vessels will be emitting unrestricted $PM_{2.5}$ for the next 20 to 30 years.

[97]Revelt, 2001.

5.10. PM Emissions of Marine Diesel Vessels

MassDEP estimated $PM_{2.5}$ emissions based on vessel and trip data provided by several sources:

- **Corps of Engineers** trip data on most domestic commercial vessels, except sightseeing, fishing and military-carrying vessels. The Corps also estimated the number of dredging projects on which emissions are based.

- **NESCAUM** data on government, and commercial fishing vessels in Boston Harbor, some of which were used to extrapolate emissions to other vessels in these categories for the entire state.

- **OLE** data on government vessels.

- **EPA** data on recreational vessels.

- **U.S. Navy and U.S. Coast Guard** data on government vessel trips.

Although most emission data were presented at the county level, data on some vessel types were only available at the statewide level.

Figure 5-4 shows that marine vessels emitted 247 tons of diesel $PM_{2.5}$ in 2002. This represented 6% of all statewide diesel emissions (see Figure 2-2). This number was further broken down:

- **C1 and C2 commercial marine vessels emitted 222 TPY, or 90%, of the diesel $PM_{2.5}$ emissions for the marine diesel vessel sector**. Since these emissions estimates were based on Corps' trip data, the emissions may include C3 engines using residual oil and non-diesel $PM_{2.5}$.

- **Small and C1 recreational vessels, despite their large number, only emitted 25 TPY, or 10% of the diesel $PM_{2.5}$ emissions for marine vessels**.

As Figure 5-5 shows, diesel $PM_{2.5}$ for each of the categories of marine diesel engines shown here is at least 92% of diesel PM_{10}. On the whole, diesel $PM_{2.5}$ represented 93% (247 TPY) of the total diesel PM_{10} (267 TPY) emitted by the marine vessel sector. C1 and C2 engines emit more $PM_{2.5}$ and coarse PM than recreational vessels.

There are several caveats to these data. The Corps of Engineers data on domestic commercial trips and the NESCAUM data on fishing vessels do not separate diesel-fueled vessels from gasoline-fueled or RO-fueled marine vessels. In this respect, diesel $PM_{2.5}$ emissions are overestimated.

On the other hand, C1 recreational vessel emissions are likely to be underestimated because EPA's geographic estimate of the number of recreational vessels in Massachusetts is slightly lower than the numbers presented by OLE and USCG. Additionally, there are little data on the number of dredging vessels other than general estimates on the number of dredging projects permitted by the Corps of Engineers. This inventory also does not capture dockside emissions produced by tugboats, workboats, or crew boats with draft less than 18 feet, or excursion vessels, except those estimated by NESCAUM for Boston Harbor in 2005. This inventory does not account for the expected minor emissions of educational vessels.

NESCAUM's data on ferries and tugboats are not included in the total estimate of marine engine emissions because the Corps data tracked them. The next several sections discuss in more detail the $PM_{2.5}$ emissions of the various categories of marine diesel engines.

5.10.1. Small and C1 Recreational Marine Vessels

According to the *Baseline Emission Inventory*, MassDEP used EPA's Office of Transportation and Air Quality (OTAQ) national NONROAD2005 Mobile Emissions Model (Version 2005a, February 2006) to determine the PM emissions of diesel engines in this sector. The NONROAD model estimates emissions from numerous engine types of off-road equipment based on national data from Power Systems Research (PSR) (the information management contractor), state, and local data inputs. Emissions are based on a 2002 equipment population distributed by age, application, power, and fuel type. This is the same model and process used to determine the emissions of the off-road, land-based diesel engines discussed in Section 4.0.

MassDEP estimated that diesel recreational vessels were responsible for 25 TPY of diesel $PM_{2.5}$ emissions in 2002. Coarse PM emissions were one TPY, for a total of 26 TPY in PM_{10} emissions. Because OLE and USCG recorded 7,280 diesel-powered recreational vessels in 2002—a 4% increase over EPA's estimate of 7,027 diesel-powered vessels on which the emissions are based—these emissions may be slightly underestimated.

5.10.2. C1 and C2 Commercial Marine Vessels

Emissions data on C1 and C2 commercial marine vessels is divided into passenger and commerce-carrying vessels, commercial fishing vessels, dredging vessels and government marine vessels.

5.10.2.1. Passenger and Commerce-Carrying Vessels

To estimate emissions from the various engines of commercial marine vessels, MassDEP used EPA's Volume IV Guidance[98] on ship movement data and data on domestic, self-propelled vessels from the Corps of Engineers. The ship movement data method calculates emissions based on the fuel use associated with the number of vessels, by draft size, in the ports of Massachusetts. Vessels with drafts of 18 feet and over generally use RO and distillate oil, whereas those with drafts less than 18 feet burn distillate oil only. Thus, these vessels use a mixture of diesel and non-diesel fuels,[99] making the PM emissions reported here a combination of diesel PM and other PM. For the purposes of this inventory, MassDEP used this data to address the emissions of C1 and C2 commercial vessels; however, EPA guidance indicates that C3 vessels may be included as well.

To estimate emissions, MassDEP evaluated data from two vessel travel modes: 1) the underway mode, where the vessel runs its main propulsion engines to maneuver in and out of port; and 2) the dockside mode, where vessels run their auxiliary diesel generator systems or main boilers to supply power for necessities such as refrigeration, heating or air conditioning.[100] MassDEP also doubled the Corps of Engineers trip data to represent round-trips to use in its commercial vessel emission estimates.

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[98]U.S. EPA, "Procedures for Emission Inventory Preparation," Volume IV: Mobile Sources. (Technical Support Div., OAQPS RTP, NC and Emission Control Technology Division. Office of Mobile Sources, Ann Arbor, Michigan, 450/4-81-02 6d, July 1989, February 1992, October 1994).
[99]U.S. Energy Information Administration, *Petroleum Marketing Monthly*, (July 2005) 155.
[100]For additional information on how MassDEP calculated marine vessel emissions, see the *Baseline Emission Inventory*.

Underway Mode Emissions

To estimate the underway emissions of domestic, self-propelled vessels of all draft sizes, MassDEP used:

- **The average travel time and speed by all vessels to and from each port and the average distance to each port.** At an estimated average speed in port of eight miles per hour and a distance of 25 miles, the average vessel travel time was 6.8 hours.

- **Fuel consumption rates.** EPA and the Mid-Atlantic and Northeast Visibility Union (MANE-VU)[101] provided fuel consumption information, based on the number of trips, fuel consumption rates by size and ship, and the average vessel travel time.

- **Emission factors**. Calculation sheets by EPA AP-42 Volume II Mobile Sources Section II-2 and MANE-VU provided emission factors by size and ship.

MassDEP then applied the emissions factors to the fuel use data to estimate emissions.

Dockside Mode Emissions

MassDEP estimated the dockside emissions of vessels with drafts of 18 feet and over. These data were based on fuel consumption rates provided by EPA and an average stay in port of one to three days. MassDEP then multiplied the fuel use for each vessel type by the appropriate emission factors.

By Waterway

Table 5-16 shows MassDEP's estimate of the dockside and underway emissions by waterway for commercial vessels with drafts of 18 feet and over. MassDEP did not calculate emissions data for a number of waterways, either because the waterways did not submit trip data to the Corps of Engineers or because the waterways do not receive vessels with drafts of 18 feet or over.

Vessels with drafts of 18 feet and over emitted the most $PM_{2.5}$ at dockside, with 65 TPY or 84% of the $PM_{2.5}$ emissions for commercial vessels with large drafts. Underway emissions, estimated at nearly 13 TPY, were 16% of the total $PM_{2.5}$ emissions for these vessels. In addition,

- **Boston's Main Waterfront had the most underway $PM_{2.5}$ emissions in 2002, with 10 TPY.** Gloucester Harbor, with 1 TPY, and Fall River, with 1 TPY, had the next highest $PM_{2.5}$ underway emissions from large commercial vessels.

- **With 52 TPY, Boston's Main Waterfront also had the most dockside $PM_{2.5}$ emissions.** Gloucester Harbor (5 TPY) and Fall River (4 TPY) also had substantial amounts of dockside emissions.

[101] MANE-VU is the regional planning organization for the Mid-Atlantic and Northeast states. EPA established MANE-VU to assess the impacts of different pollution sources of regional haze. MANE-VU members include Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, the Penobscot Indian Nation, the St. Regis Mohawk Tribe, Rhode Island, and Vermont.

A Look at Boston Harbor Emissions

Using an emission equation from Starcrest Consulting Group for its *Scoping Study* of Boston Harbor, NESCAUM estimated PM_{10} emissions from ferries, excursion vessels, government vessels, towboats/tugboats, and dredging vessels operating in the harbor in 2005. Emissions estimates were based on each vessel's hours of operation or fuel consumption, engine horsepower, and EPA's PM_{10} emission factors for C1 engines with less than 1,000 hp. Emissions estimates were also based on emission factors from Entec UK Limited for C1 engines with over 1,000 hp and C2 engines. NESCAUM noted that Entec's emission factors for PM_{10} produced 11% to 40% higher emission estimates than EPA's emission factors.

Some of the trip data are presumed to be a subset of the Corps of Engineers' 2002 trip data for Boston Harbor. The numbers presented here were not adjusted to 2002 data. NESCAUM did not estimate $PM_{2.5}$.

***Table 5-15. Estimated Emissions of Certain Vessels Operating in Boston Harbor*[1]**

Boston Harbor Craft	Number	PM_{10} Emissions (TPY)
Government Vessels	46	1.95
Dredging	1	0.21
Ferries/Excursion Vessels 20	35	13.71
Tow Boats/Push Boats/Tug Boats	15	4.01
Total	*97*	*19.88*

SOURCE: NESCAUM, 2006

As NESCAUM noted in its report, 70% of the PM emissions from the harbor craft inventory came from ferries and excursion vessels. Although there are 46 government vessels and 35 ferries and excursion vessels, the ferries and excursion vessels emitted more PM than other vessels because they have higher activity levels and horsepower (commuter boats operate an average of 14 hours a day). A list of the harbor craft and their emissions is in Appendix O.

Table 5-16. Dockside & Underway Emissions, Domestic C1 and C2 Commercial Vessels, Draft >18 Feet (TPY)

			Dockside		Underway		Total	
Port	County	Number of Trips	PM2.5	PM10	PM2.5	PM10	PM2.5	PM10
Cape Cod Canal	Barnstable	41	0.2	0.2	0.1	0.1	0.3	0.3
Fall River Harbor	Bristol	84	4.4	4.8	0.9	0.9	5.3	5.7
Gloucester Harbor	Essex	92	4.8	5.2	0.9	1.0	5.7	6.2
Town River	Norfolk	7	0.4	0.4	0.1	0.1	0.5	0.5
Weymouth Fore River	Norfolk	4	0.2	0.2	0.0	0.0	0.2	0.2
Subtotal	*Norfolk*	*11*	*0.6*	*0.6*	*0.1*	*0.1*	*0.7*	*0.7*
Plymouth Harbor	Plymouth	8	0.4	0.5	0.1	0.1	0.5	0.6
Mystic River	Suffolk	13	0.7	0.7	0.1	0.1	0.8	0.8
Chelsea River	Suffolk	25	1.3	1.4	0.3	0.3	1.6	1.7
Boston.Main Waterfront	Suffolk	1,000	52.4	57.0	10.1	11.0	62.5	68.0
Subtotal	*Suffolk*	*1,038*	*54.4*	*59.1*	*10.5*	*11.4*	*64.9*	*70.5*
Total		*1,274*	*64.8*	*70.5*	*12.6*	*13.7*	*77.4*	*84.2*

* Due to the absence of trip data provided to the Corps of Engineers or to the absence of vessels with drafts over 18 feet in the waterway, MassDEP did not estimate emissions from the following harbors: Beverly, Cohasset, Cuttyhunk, Edgartown, Falmouth/Wood's Hole, Green, Hyannis, Lynn, Marblehead, Martha's Vineyard, Menemsha Creek, Nantucket, New Bedford/Fairhaven, Newburyport, Provincetown, Vineyard Haven, and Salem or for, Fort Pt. Channel, Weymouth Back River, Westport River and Island End River.

Table 5-17 shows MassDEP's estimate of the underway emissions of vessels with drafts of less than 18 feet. For domestic commercial vessels in this group, total $PM_{2.5}$ underway emissions were 124 TPY—ten times as much as the underway emissions of vessels with drafts of 18 feet and over. Also,

- **Edgartown Harbor received the most $PM_{2.5}$ underway emissions, with 40 TPY**. Small vessels traveling to or in Boston's Main Waterfront emitted a substantial amount of $PM_{2.5}$ as well (33 TPY), as did those traveling to Nantucket Harbor (20 TPY) and Vineyard Haven (19 TPY).

- **Other significant $PM_{2.5}$ underway emission sources were small vessels** traveling to and in Hyannis Harbor (8 TPY).

Table 5-17. Underway Emissions, Domestic C1 and C2 Commercial Vessels, Draft <18 Feet (TPY)

		12-17 FT			6-11 FT			Total		
Port	County	Trips	$PM_{2.5}$	PM_{10}	Trips	$PM_{2.5}$	PM_{10}	Trips	$PM_{2.5}$	PM_{10}
Falm/Woods Hole	Barnstable	-	0.0	0.0	785	0.5	0.5	785	0.5	0.5
Cape Cod Canal	Barnstable	108	0.1	0.1	80	0.0	0.0	188	0.1	0.1
Cuttyhunk Harbor	Barnstable	-	0.0	0.0	8	0.0	0.0	8	0.0	0.0
Hyannis Harbor	Barnstable	-	0.0	0.0	13,229	8.4	9.1	13,229	8.4	9.1
Provincetown	Barnstable	-	0.0	0.0	1	0.0	0.0	1	0.0	0.0
Subtotal	*Barnstable*	*108*	*0.1*	*0.1*	*14,103*	*8.9*	*9.6*	*14,211*	*9.0*	*9.7*
Fall River Harbor	Bristol	100	0.3	0.3	100	0.1	0.1	200	0.3	0.4
N.Bed/Fairhaven	Bristol	200	0.6	0.6	1,204	0.8	0.8	1,404	1.3	1.4
Westport River	Bristol	-	0.0	0.0	3	0.0	0.0	3	0.0	0.0
Subtotal	*Bristol*	*300*	*0.9*	*0.9*	*1,307*	*0.9*	*0.9*	*1,607*	*1.6*	*1.8*
Vineyard Haven	Dukes	4,588	12.8	13.9	10,000	6.3	6.9	14,588	19.1	20.8
Edgartown Harbor	Dukes	-	0.0	0.0	62,818	39.7	43.2	62,818	39.7	43.2
Subtotal	*Dukes*	*4,588*	*12.8*	*13.9*	*72,818*	*46.*	*50.1*	*77,406*	*58.8*	*64.0*
Salem Harbor	Essex	1	0.0	0.0	1	0.0	0.0	2	0.0	0.0
Gloucester Harbor	Essex	100	0.3	0.3	100	0.1	0.1	200	0.3	0.4
Newburyport Harbor	Essex	-	0.0	0.0	239	0.2	0.2	239	0.2	0.2
Marblehead Harbor	Essex	-	0.0	0.0	-	0.0	0.0	-	0.00	0.0
Subtotal	*Essex*	*101*	*0.3*	*0.3*	*340*	*0.3*	*0.3*	*441*	*0.5*	*0.6*
Nantucket Harbor	Nantucket	5,902	16.4	17.9	5,000	3.2	3.44	10,902	19.6	21.3
Subtotal	*Nantucket*	*5,902*	*16.4*	*17.9*	*5,000*	*3.2*	*3.44*	*10,902*	*19.6*	*21.3*
Town River	Norfolk	7	0.0	0.0	2	0.0	0.0	9	0.0	0.0
Weymouth Fore Riv	Norfolk	7	0.0	0.0	7	0.0	0.0	14	0.0	0.0
Weymouth Back Riv	Norfolk	-	0.0	0.0	1,724	1.1	1.2	1,724	1.1	1.2
Subtotal	*Norfolk*	*14*	*0.0*	*0.0*	*1,733*	*119*	*1.2*	*1,747*	*1.1*	*1.2*
Plymouth Harbor	Plymouth	5	0.0	0.0	4	0.0	0.0	9	0.0	0.0
Subtotal	*Plymouth*	*5*	*0.0*	*0.0*	*4*	*0.0*	*0.0*	*9*	*0.0*	*0.0*
Mystic River	Suffolk	12	0.0	0.0	12	0.0	0.0	24	0.0	0.0
Chelsea River	Suffolk	40	0.1	0.1	40	0.0	0.0	80	0.1	0.2
Boston Main Wtrfrnt	Suffolk	10,000	27.8	30.3	8,413	5.3	5.8	18,413	33.2	36.0
Fort Pt. Channel	Suffolk	-	0.0	0.0	-	0.0	0.0	-	0.0	0.0
Island End River	Suffolk	22	0.	0.	22	0.0	0.0	44	0.	01
Subtotal	*Suffolk*	*10,074*	*27.9*	*30.4*	*8,487*	*5.3*	*5.8*	*18,561*	*33.3*	*36.3*
Total		21,087	58.5	63.6	103,788	65.6	71.3	124,875	124.1	134.9

* Due to the absence of trip data provided to the Corps of Engineers or to the absence of vessels with drafts over 18 feet in the waterway, MassDEP did not estimate emissions from the following harbors: Beverly, Cohasset, Green, Lynn, Marblehead, Martha's Vineyard, Menemsha Creek, or Fort Pt. Channel.

SOURCE: MassDEP, 2006.

5.10.2.2. C1 Commercial Fishing Vessels

MassDEP used NESCAUM's 1998 *Heavy-Duty Engine Emissions Inventory*[102] to estimate the underway and dockside emissions of fishing vessels for the *Baseline Emission Inventory* (the Corps did not track trips of fishing vessels). Fishing vessels emit $PM_{2.5}$ at dockside as they idle their auxiliary engines to refrigerate and unload their catch. NESCAUM tracked the number of gasoline and diesel-

[102]NESCAUM, *Heavy-Duty Engine Emissions in the Northeast*, Chapter 3, "Boston Harbor Marine Vessel Emission Inventory," October 1998.

fueled fishing vessels docking at the Port of Boston, using data from DMF. NESCAUM's emission estimates were based on the average horsepower, mode of throttle operation, fuel consumption, and emission factors of the following 421 fishing vessels and 17,800 vessel trips:

- 421 commercially licensed fishing vessels (not trips)
- 14,000 lobster vessel trips
- 1,000 striped bass and other fin fishing trips
- 2,500 shellfish vessel trips

NESCAUM then scaled the Port of Boston emissions data to other ports in the state based on tons of freight traffic from the Corps of Engineers. Using these factors, NESCAUM estimated that fishing vessels emitted 9 TPY of $PM_{2.5}$, or 93% of PM_{10}. The 9 TPY represents 4% of the entire marine diesel vessel $PM_{2.5}$ sector. Since these data are based largely on the trips of gasoline-fueled lobster, fin, striped bass and shellfish fishing vessels, they overestimate diesel $PM_{2.5}$ emissions.

5.10.2.3. C1 Commercial Dredging Marine Vessels

Virtually all dredging vessels operate on diesel fuel.[103] Dredges may be used for harbor maintenance, digging new channels, or deepening existing channels. The Corps of Engineers estimated that 30 dredging projects occur each year,[104] with an average of one vessel operating on each project. NESCAUM calculated that one dredging vessel[105] in Boston Harbor emitted less than one TPY of PM_{10} during 2005. Based on these data, MassDEP estimated PM_{10} emissions from this source to be 6.3 TPY. Using EPA's recommendation that $PM_{2.5}$ is 97% of $PM_{10,}$[106] MassDEP then estimated $PM_{2.5}$ emissions at 6.1 TPY.

5.10.2.4. C1 Government Marine Vessels

MassDEP based its estimate of government marine vessel emissions on a mix of diesel-fueled and RO-fueled vessels tracked by the Coast Guard, U.S. Navy, OLE and NESCAUM. According to the *Baseline Emission Inventory*, MassDEP found that Navy and U.S. Coast Guard vessels made a total of 69 trips to several ports in Massachusetts. The Coast Guard used two diesel coast guard cutters, making 15 to 20 trips annually. The Navy Yard in Charlestown reported that naval vessels made 45 visits from the Port of Boston and one visit each at Gloucester and Beverly harbors. The Navy Yard in New Bedford reported two visits of naval ships, which most likely operated on RO or were steam powered.

Because the number of known trips was very small, military vessel emissions were very low (Table 5-18). $PM_{2.5}$ emissions were a little over two TPY, which is 1% of the marine vessel $PM_{2.5}$ sector. Suffolk and Nantucket counties registered the most military vessel emissions in 2002.

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[103]Mikutowicz, 2007.
[104]Farese and Adams, 2006.
[105]NESCAUM categorized the dredging vessel as a C2 vessel.
[106]ICF, 2006.

Table 5-18. Military Marine Vessel Emissions, By County (TPY)

County	PM2.5	PM10
Barnstable	0.1	0.1
Berkshire	0.0	0.0
Bristol	0.1	0.1
Dukes	0.7	0.8
Essex	0.1	0.1
Franklin	0.0	0.0
Hampden	0.0	0.0
Hampshire	0.0	0.0
Middlesex	0.0	0.0
Nantucket	0.2	0.3
Norfolk	0.0	0.0
Plymouth	0.0	0.0
Suffolk	1.2	1.3
Worcester	0.0	0.0
Total	*2.4*	*2.6*

SOURCE: MassDEP, 2007.

Furthermore, NESCAUM estimated that 46 government marine vessels in Boston Harbor emitted 2 TPY of PM, or 0.04 TPY per vessel in 2005 (Table 5-19). Using EPA's recommendation that $PM_{2.5}$ is 97% of PM_{10}, MassDEP estimated the $PM_{2.5}$ annual tonnage at 1.9 TPY and per vessel $PM_{2.5}$ emissions at less than one ton per year. By applying the per vessel emission rate to the 40 government vessels registered by OLE, MassDEP estimated $PM_{2.5}$ emissions to be 1.6 TPY.

Table 5-19. Government Marine Vessel Emissions (TPY)

Vessel Type	Number of Vessels/Trips	PM2.5	PM10	Data Source
Military	69 trips	2.4	2.6	MassDEP, 2006
Government-Boston Harbor	46 vessels	1.9	2.0	NESCAUM, 2006
Government	40 vessels	1.6	1.7	OLE, 2006
Total	-----	*5.9*	*6.3*	--

Some unavoidable double counting may be present in these estimates. Some OLE vessels and some of the *Baseline Emission Inventory*'s naval ship trips may be double-counted in the NESCAUM inventory.

Table 5-20 shows MassDEP's estimate of PM emissions for commercial vessels of all draft sizes (some C1, mostly C2, and some C3 engines) at the county and statewide level in 2002. The fishing vessels emissions include both underway and dockside emissions:

- **Statewide, underway emissions of $PM_{2.5}$ were more than twice as great as dockside emissions.** Based on Corps of Engineers trip data, $PM_{2.5}$ underway emissions were 137 TPY and $PM_{2.5}$ dockside emissions were 65 TPY.

- **Suffolk County, with 49% (103 TPY) of state marine vessel emissions and representing the Main Boston Waterfront, Chelsea River and other areas, received the most $PM_{2.5}$ emissions from domestic commercial marine vessels**. Dukes County, representing Edgartown, Vineyard Haven, and Martha's Vineyard, and Nantucket County, representing

Nantucket Harbor, also received significant total $PM_{2.5}$ emissions (61 and 21 TPY, respectively).

- **$PM_{2.5}$ underway emissions were highest in Dukes County (59 TPY).** Suffolk County, with 44 TPY, and Nantucket County, with nearly 20 TPY, were also recipients of significant amounts of $PM_{2.5}$ underway emissions.

- **$PM_{2.5}$ emissions from fishing vessels were highest in Suffolk County (4 TPY).** Dukes County, covering the Martha's Vineyard area, received nearly 3 TPY in $PM_{2.5}$ emissions from fishing vessels.

Table 5-20. Total Estimated Domestic Commercial Marine Vessel Emissions (TPY)

	PM2.5						*PM10*					
County	Underway	Dockside	Fishing Vessels	Dredging	Government	*Total*	Underway	Dockside	Fishing Vessels	Dredging	*Government*	*Total*
Barnstable	9.1	0.2	0.4	-	-	*9.7*	9.9	0.2	0.4	-	-	*10.5*
Berkshire	0.0	0.0	0.0	-	-	*0.0*	0.0	0.0	0.0	-	-	*0.0*
Bristol	2.5	4.4	0.3	-	-	*7.2*	2.7	4.8	0.3	-	-	*7.9*
Dukes	58.8	0.0	2.6	-	-	*61.4*	63.9	0.0	2.8	-	-	*66.8*
Essex	1.4	4.8	0.3	-	-	*6.5*	1.6	5.2	0.3	-	-	*7.1*
Franklin	0.0	0.0	0.0	-	-	*0.0*	0.0	0.0	0.0	-	-	*0.0*
Hampden	0.0	0.0	0.0	-	-	*0.0*	0.0	0.0	0.0	-	-	*0.0*
Hampshire	0.0	0.0	0.0	-	-	*0.0*	0.0	0.0	0.0	-	-	*0.0*
Middlesex	0.0	0.0	0.0	-	-	*0.0*	0.0	0.0	0.0	-	-	*0.0*
Nantucket	19.6	0.0	0.9	-	-	*20.5*	21.3	0.0	0.9	-	-	*22.2*
Norfolk	1.3	0.6	0.1	-	-	*1.9*	1.4	0.6	0.1	-	-	*2.1*
Plymouth	0.1	0.4	0.0	-	-	*0.5*	0.1	0.5	0.0	-	-	*0.6*
Suffolk	43.9	54.4	4.3	-	-	*102.6*	47.7	59.1	4.7	-	-	*111.5*
Worcester	0.0	0.0	0.0	-	-	*0.0*	0.0	0.0	0.0	-	-	*0.0*
Total	*136.7*	*64.8*	*8.9*	-	-	*210.4*	*148.6*	*70.4*	*9.6*	-	-	*228.6*
Statewide				6.1	5.9	12.0				6.3	6.3	12.6
Grand Total						**222.4**						**241.2**

Emission estimates were not developed for the few educational vessels estimated to be operating in Massachusetts because data were not available.

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6.0. Diesel Locomotive Engines

According to the *Baseline Emission Inventory*, railroad locomotives are primarily electric or diesel-electric powered. Electric locomotives are powered by electricity generated at stationary power plants, which are inventoried as point sources. These locomotives are not included in this inventory. The diesel-electric locomotives discussed here use diesel engines and generators to produce their electrical power.

Locomotives are further broken down into line-haul locomotives that provide point-to-point service for cargo, switchyard locomotives that move cargo and engines at terminals, and passenger locomotives. Some interstate rail (i.e., the Boston to New York City rail line operated by Amtrak[107]) has converted to electrified track in recent years; however, other lines (i.e., Amtrak's Boston to Albany line, New Haven to Springfield line and Boston to Portland line) continue to use diesel fuel. Intrastate commuter rail engines run on diesel fuel.[108]

6.1. Data Sources

The Central Transportation Planning Staff (CTPS), the Association of American Railroads (AAR) and individual rail companies provided data on the number of locomotives and track miles in Massachusetts. The MBTA, AAR, EPA, and other sources provided data that MassDEP used to estimate locomotive emissions.

6.2. Number of Diesel Locomotives

MassDEP obtained data on the number of line-haul, switchyard, and commuter rail engines for local, regional and interstate railroads (Table 6-1). In some cases, rail companies use their line-haul engines to serve as switchyard engines. Trains are classified in three ways: Class 1 railroads, regional railroads and local railroads. As defined by the Surface Transportation Board in 2003, a Class I railroad is a railroad with operating revenues of at least $277.7 million. A regional railroad is a non-Class I, line-haul railroad operating 350 or more miles of road or with revenues of at least $40 million or both. A local railroad is neither a Class I nor a regional railroad that is engaged primarily in line-haul service.

Table 6-1 shows the average number of trains that operate in Massachusetts on a daily basis, as estimated by representatives at several railroad companies. Data for the rail lines represent 2007 data; however, since there was no substantial growth in the number of trains since 2002 the data were not adjusted.[109]

[107] Amtrak is formally known as the National Railroad Passenger Corporation.
[108] Anne S. McGahan, Central Transportation Planning Staff (CTPS), Boston, MA. Telephone conversation with the author, November 2005.
[109] Maurice O'Connell, CSX Corporation. Telephone conversations with the author, June 2007; Dave Rutkowski, Providence and Worcester Railroad. Telephone conversation with the author, Mar 13, 2007; Robert Bass, Housatonic Railroad. Telephone conversation with the author, April 27, 2007.

Table 6-1. Number of Diesel Locomotive Engines in Massachusetts

		Number			
Type of Railroad	Railroad Company	Miles Operated in MA	Line-Haul or Passenger Rail Engines	Switchyard Engines	Total Engines
Freight					
Class I	CSX Transportation [a]	434	40	26	66
Regional	Pan Am Railways [b, c]	407	50	0	50
	Providence and Worcester Railroad [d]	103	4	0	4
	New England Central Railroad [e]	55	9	2	11
Local	Bay Colony Railroad	131	9	4	13
	Housatonic Railroad [f]	38	3	0	3
	Massachusetts Central Railroad	28	3	N/A	3
	Pioneer Valley Railroad	17	3	4	7
Switchyard/ Terminal	Grafton & Upton Railroad [g]	2	1	1	2
	Fore River Transportation	4	2	2	4
Passenger	Cape Cod Central Railroad	N/A	3	N/A	3
	MBTA – commuter rail [h]	256	80	3	83
	Amtrak [i]	115 [j]	9	1	10
Total		*1,590*	*216*	*43*	*259*

[a] O'Connell, 2007.
[b] Formerly Guilford Railroad.
[c] Robert Culliford, Pan Am Railways. Telephone conversation with the author, May 22, 2007.
[d] Rutkowski, 2007.
[e] Bob Richardson, New England Central Railroad. E-mail to the author, April 12, 2007.
[f] Bass, 2007.
[g] Meg Preissler, *Switchyard Locomotives: Emission Reduction Potential with Auxiliary Power Units*. (EPA Region I: Barnard College, Columbia University, no date).
[h] CTPS, 2005.
[i] Rob Graham, Amtrak. Telephone conversation with the author, Mar. 30, 2007.
[j] Amtrak track miles are only for Boston to Rhode Island, Boston to Worcester, and Boston to Haverhill. Paul Joy, Amtrak. Telephone conversation with the author, April 27, 2007.

6.3. $PM_{2.5}$ Emission Standards and Fuel

6.3.1. $PM_{2.5}$ Emission Standards

In 1997, EPA set emission standards for locomotives for the first time based on the date the locomotive was manufactured.[110] Standards apply to engines originally manufactured in 1973 through 2001 and at any time they are remanufactured. This is a key point since locomotives are typically rebuilt every five to seven years, or five to 10 times during their 40-year lifetime.[111] Electric locomotives, historic steam-powered locomotives and locomotives originally manufactured before 1973 are not regulated.

[110] 63 FR 18997, April 16, 1998.
[111] U.S. EPA, Office of Transportation and Air Quality, Air and Radiation, "Program Update: Reducing Air Pollution from Nonroad Engines" (EPA420-F-03-011 April 2003).

Table 6-2. PM Emission Standards of Locomotives

Duty Cycle	Tier	Model Year Effective	PM Standard (g/bhp-hr)
Line-Haul	0	1973	0.60
	1	2002	0.45
	2	2005	0.20
Switchyard	0	1973	0.72
	1	2002	0.54
	2	2005	0.24

SOURCE: www.dieselnet.com/standards/us/loco.html.

EPA's regulations for Tier 0, 1, and 2 emission standards reduce PM emissions from new train engines by about 50% and do not require current emission controls to attain the emission standards. However, even with these standards, locomotives and marine engines emit pollutants at much higher rates than trucks, buses, or off-road engines. The National Association of Clean Air Agencies (NACAA) reported that a train meeting the Tier 2 standards emits as much PM over its life as nearly 500 trucks. [112]

In March 2007, EPA proposed new emission standards for new line-haul, switchyard, and passenger locomotives that are projected to reduce PM emissions by 90%.[113] The new Tier 3 and 4 emission standards would respond to the use of ULSD fuel in new engines and would take effect in 2009 and 2015, respectively.

EPA has also proposed tightening emission standards for existing train engines when they are remanufactured. If the technology is available, the standards could apply to Tier 1 engines in 2008 or 2010, and to Tier 2 engines in 2013.

According to EPA, the relative contribution of these diesel engines to PM is expected to increase due to the expected future growth in the use of these engines. Without new controls and with the decrease in emissions from on-road and off-road land-based engines, EPA estimates that locomotives and marine diesel engines together will generate about 65% of national mobile source diesel $PM_{2.5}$ emissions by 2030.[114] This would represent a six-fold increase in emissions from 1996 when emissions were reported at 10% of the national mobile source diesel $PM_{2.5}$ emissions inventory.[115]

6.3.2. Diesel Fuel

In 2004, EPA required locomotives to use a low sulfur diesel fuel of 500 ppm by July 2007.[116] This sulfur level will decrease to 15 ppm in June 2012 in order to be compatible with diesel emission control technologies for locomotives.

[112]State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials, "Danger in Motion: It's Time to Clean Up Trains and Boats," February 2006. (NACAA is the new name for these two organizations.)
[113]U.S. EPA, "Regulatory Announcement: EPA Proposal for More Stringent Emissions Standards for Locomotives and Marine Compression-Ignition Engines" (EPA420-F-07-015, March 2007).
[114]Ibid.
[115]Ibid.
[116]69 FR 39858, June 29, 2004.

6.4. Age

Nationwide, locomotive engines have an average life span of 40 years and, as noted above, are remanufactured five to ten times during their service life. Data on the age of New England Central Railroad's engines lends supports to this national statistic. The average age of NECR's engines, none of which have been rebuilt, is 37 years.[117]

Providence and Worcester Railroad's engines are slightly newer than these national data. P&W estimates that at least 13 of the 30 engines in its regional fleet are model year 1988 and the median model year of the entire fleet is 1982, for an average age of 20 years for the 2002 inventory.[118]

6.5. PM Emissions of Diesel Locomotive Engines

According to the *Baseline Emission Inventory*, MassDEP used the estimated quantity of diesel fuel consumed for railroad and switchyard operations in the state as the primary emission factor in estimating PM emissions. The *Baseline Emission Inventory* referenced the following sources to estimate PM emissions:

- **EPA and MANE-VU Emission Calculation Sheets** for railroads for emission factors per gallon of diesel fuel for line and switchyard operations;
- **The MBTA** for diesel fuel use by its entire commuter rail fleet for 1999;
- **The Association of American Railroads (AAR)** for annual data up to 1999 on the total number of employees, carloads and other data; and,
- **The Massachusetts Executive Office of Transportation State Rail Plan** for in-state track miles to further apportion rail emissions to counties.

The *Inventory* also reported that railroad traffic is relatively constant throughout the year. For more information on how MassDEP calculated the emissions of locomotives in Massachusetts, please see the *Baseline Emission Inventory*.

Based on these data sources, MassDEP estimated that railroad locomotives emitted 142 TPY of diesel $PM_{2.5}$. Table 6-3 shows the emissions of switchyard and line-haul locomotives, by rail line. Key findings were:

- **MBTA passenger trains emitted more diesel $PM_{2.5}$ than all other railroads combined**, based on currently available data.
- **CSX and Pan Am Railway locomotives were the next highest $PM_{2.5}$ emitters** with almost 33 TPY and 12 TPY of diesel $PM_{2.5}$, respectively.
- **Line-haul locomotives emitted five times as much diesel $PM_{2.5}$ as switchyard locomotives in 2002.** This is not surprising since they travel much more than switchyard trains, although switchyard trains idle as many as 4,000 hours each year according to EPA.

[117] Richardson, 2007.
[118] Rutkowski, 2007.

Table 6-3. $PM_{2.5}$ vs. PM_{10} Emissions, Switchyard and Line-Haul Engines (TPY)

Type of Railroad	Railroad Company	Line-Haul/ Commuter Rail			Switchyard			Total		
		$PM_{2.5}$	Coarse	PM_{10}	$PM_{2.5}$	Coarse	PM_{10}	$PM_{2.5}$	Coarse	PM_{10}
Freight										
Class 1	CSX Transportation	32.6	3.6	36.2	0.0	23.4	23.4	32.6	27.0	59.6
Regional	Pan Am Railways	5.6	0.6	6.2	6.0	0.7	6.7	11.6	1.2	12.8
	Providence and Worcester Railroad	0.8	0.1	0.9	4.5	0.5	5.0	5.3	0.6	5.9
	New England Central Railroad [a]	0.01	--	0.01	0.8	--	0.8	0.8	--	0.8
Local	Bay Colony Railroad	0.4	0.1	0.5	5.2	0.6	5.8	5.7	0.6	6.3
	Housatonic Railroad	0.4	--	0.4	0.8	--	0.8	1.1	0.2	1.3
	Massachusetts Central Railroad	0.3	0.1	0.4	1.5	0.2	1.7	1.8	0.2	2.0
	Pioneer Valley Railroad	0.0	--	0.0	2.3	0.2	2.5	2.2	0.3	2.5
Switchyard/ Terminal	Grafton & Upton Railroad	0.02	--	0.02	0.8	--	0.8	0.8	0.1	0.9
	Fore River Transportation	0.2	--	0.2	0.0	--	0.0	0.2	--	0.2
Passenger	MBTA	75.1	8.3	83.4	0.0	--	0.0	75.1	8.3	83.4
	Amtrak	3.8	0.4	4.2	1.5	0.2	1.7	5.2	0.6	5.8
Total		*119.2*	*13.2*	*132.4*	*23.2*	*26.0*	*49.2*	*142.4*	*39.2*	*181.6*

[a] The *Baseline Emission Inventory* lists data for the New England Central Railroad (NECR) and the Vermont Central Railroad. Since the Vermont Central Railroad sold its rail line holdings to NECR in 1995, this diesel $PM_{2.5}$ inventory only shows data for NECR.

SOURCE: MassDEP, 2006.

Locomotive diesel $PM_{2.5}$, emissions were 78% (142 TPY) of PM_{10} emissions (182 TPY). Coarse PM consisted of 40 tons or 22%. Figure 6-1 shows that switchyard engines emitted more coarse PM than $PM_{2.5}$—the only engine group in the inventory to do so.

6.6. References for Locomotive Diesel Engines

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U.S. EPA. *Regulatory Announcement: EPA Proposal for More Stringent Emissions Standards for Locomotives and Marine Compression-Ignition Engines*. EPA420-F-07-015. March 2007.

7.0. Stationary Diesel Engines

Stationary diesel engines are typically small engines and turbines that are used, for example, at power, chemical, and manufacturing plants to generate electricity and to power pumps and compressors. They are also used in emergencies to produce electricity and pump water for flood and fire control. Stationary sources that combust diesel fuel typically run a limited number of hours when they serve as emergency or backup generators.

7.1. Data Sources

MassDEP's Stationary Source Emission Inventory System (SSEIS) database tracks PM emissions data submitted to MassDEP by stationary sources. MassDEP mails a source registration form each year to Massachusetts' factories, power plants, and other large business facilities that have the potential to emit more than a certain threshold amount of pollutants. For sources below the threshold amounts, MassDEP mails source registration forms triennially. Facilities are required to report emissions to the ambient air of the inventoried pollutants and submit the form to MassDEP. MassDEP records the facility data in the SSEIS database.[119] MassDEP used these data to identify the number of stationary diesel engines in Massachusetts and their diesel $PM_{2.5}$ emissions.

7.2. Number of Stationary Diesel Engines

Using the SSEIS database, MassDEP identified 1,081 stationary sources combusting diesel fuel for all EPA Source Classification Codes (SCC) associated with diesel. These sources are categorized under the general EPA Source Classification Code, "Internal Combustion Engines." This classification contained units in three major industry groups: electric generation, industrial, and commercial/ institutional. The specific types of units combusting diesel were turbines, reciprocating engines, co-generating turbines, and co-generating reciprocating engines.

Because industry groups are required to report emissions to MassDEP at different frequencies (large units must report annually, smaller units report less frequently), these facilities reported data from 1994 to 2003. The majority of units (668 of the 1,081 units) reported PM emissions data for calendar year 2003. These engines used No. 1, 2 or 4 diesel oil or fuel. Appendix P contains a list of the Massachusetts stationary source units that reported to MassDEP the use of diesel combustion and their associated PM emissions.

7.3. Growth in Stationary Diesel Engines

After September 11, 2001, MassDEP received an increased number of applications for new emergency engine installations for those facilities needing uninterrupted power supply. Applications for emergency engine permits are expected to continue, although specific growth projections are not available.[120]

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[119]MassDEP, *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia*, June 2006.
[120]Robert Donaldson, MassDEP. E-mail communication with the author, Oct. 23. 2006.

7.4. Ownership

Appendix P lists the owners of the stationary diesel engines currently operating in Massachusetts.

7.5. $PM_{2.5}$ Emission Standards and Fuel

7.5.1. $PM_{2.5}$ Emission Standards

PM emission standards for the stationary diesel engines registered in SSEIS were not in place before 2005. Emissions controls were established on a case-by-case review for Best Available Control Technology (BACT). In September 2005, MassDEP established PM emission standards for certain small stationary sources with rated power output equal to or greater than 50 kW, that are constructed, substantially reconstructed, or altered on or after March 23, 2006.[121] MassDEP's standards are shown in Table 7-1.

Table 7-1. PM Emission Standards for Small Stationary Diesel Engines

Installation Date	PM (Liquid Fuel Only)
March 23, 2006	$\leq$ 1MW - 0.7 lbs/MWh > 1 MW - 0.09 lbs/MWh
On and after Jan. 1, 2008	0.07 lbs/MWh
On and after Jan. 1, 2012	0.03 lbs/MWh

SOURCE: 310 CMR 7.26(43).

In addition, EPA promulgated a new rule[122] to reduce emissions from stationary diesel engines in June 2006. These New Source Performance Standards (NSPS) will limit PM emissions to the same levels required for diesel off-road vehicles.[123] Beginning in model year 2007, engine manufacturers are required to certify that all new,[124] modified[125], or reconstructed stationary diesel engines meet the same stringent PM emission standards as the Tier 1, 2, and 4 PM[126] standards for off-road engines. Stationary emergency diesel engines must meet Tier 3 and Tier 4 emission standards; however, Tier 4 requirements do not require add-on controls. Beginning with 2011 model year engines, add-on controls will be required to achieve the emission limits for non-emergency engines.

[121] 310 CMR 7.26(43).
[122] 40 CFR, Chapter 1, Part 60.
[123] EPA proposed the original NSPS for stationary diesel engines in 1979 but these were never finalized.
[124] A new stationary diesel engine is one that is constructed or ordered, after July 11, 2005, the date the proposed standards were published in the Federal Register and manufactured after April 1, 2006.
[125] Stationary diesel engines that start modification or reconstruction after July 11, 2005 are subject to the rule.
[126] U.S. EPA, "Regulatory Announcement: New Emission Standards for Nonroad Diesel Engines," EPA420-F-98-034, August 1998. Available on-line at: http://www.epa.gov/nonroad-diesel/frm1998/f98034.htm. The 1998 federal rule explained that EPA did not implement the Tier 3 standards for $PM_{2.5}$ because the agency preferred to discuss the standards at a 2001 feasibility review.

7.5.2. Diesel Fuel

EPA required engine owners to use diesel fuel with a sulfur content of 500 ppm, the maximum allowable sulfur level for on-road diesel vehicles, in 2007. In 2011, the sulfur content will decrease to 15 ppm, the sulfur level of ULSD fuel.

7.6. Age

Manufacturers of stationary diesel engines estimate that each engine has a life expectancy of eight to ten years.[127] Turnover of these engines is therefore expected to be frequent.

7.7. PM Emissions of Stationary Diesel Engines

According to MassDEP's *Baseline Emission Inventory*, the most common method for calculating point source emissions involves the use of emission factors in combination with activity factors. The activity factor is the quantity and type of material or fuel used. SSEIS has a built-in table of EPA emission factors that are based on source classification codes related to the specific source process. A single facility may report emissions for multiple source processes. MassDEP factors in the facilities' control equipment and its estimated effectiveness when estimating emissions for these sources.

Data from source-specific emission tests or continuous emission monitors (CEMs) are usually preferred for estimating a stationary source's emissions because they provide the best representation of the tested source's emissions. However, test data from individual sources are not always available and, even then, they may not reflect the variability of actual emissions over time. Thus, emission factors are frequently the best or only method available for estimating emissions, in spite of their limitations. For this inventory, MassDEP incorporated emission data as reported to it on the source registration forms by facilities; these data were derived from CEMs or from other methods

If the facility did not supply emissions data, MassDEP staff calculated emissions by inputting activity data such as fuel use into MassDEP's database to be multiplied by AP-42 emission factors by SCCs.[128] Although 1,081 stationary diesel engines combusted diesel over this period, the PM emissions from these sources were not large, consisting of 63 tons of diesel PM_{10}. Of the 63 tons, 32 tons consisted of diesel $PM_{2.5}$ or 51% of the PM_{10} emissions for this sector. In relation to the rest of the Massachusetts diesel $PM_{2.5}$ inventory, stationary diesel engines emitted less than one percent of the diesel $PM_{2.5}$ in the state.

[127] Donaldson, 2006.
[128] MassDEP, 2006.

7.8. References for Stationary Diesel Engines

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U.S. EPA. "Regulatory Announcement: New Emission Standards for Nonroad Diesel Engines." EPA420-F-98-034. August 1998.

8.0. Area Source Diesel Engines

According to MassDEP's *Baseline Emission Inventory*,[129] area sources are defined as those sources that generate less than 10 TPY of VOCs and NOx and less than 100 TPY of CO, SO_2, PM_{10}, $PM_{2.5}$ and NH_3. Area source engines consist of emissions sources that are small and numerous, and that have not been inventoried as specific point, mobile, or biogenic sources. Gasoline stations and dry cleaning establishments are examples of facilities that are generally treated as area sources.

The only area source that burns diesel fuel is the hot applied asphalt roofing source category. Roofing contractors must burn diesel fuel to heat the asphalt used in roofing applications. Other categories of area sources relating to diesel fuel are not included in this inventory since they do not combust diesel fuel; rather the area sources may spill diesel fuel (such as a tanker carrying fuel oil), which releases VOCs, not $PM_{2.5}$. In addition, combustion activities relating to residential, commercial, institutional and industrial boilers, furnaces, and heaters are not included in this inventory because they do not use diesel fuel; rather, these sources burn distillate and residual fuel oils, neither of which are considered to be diesel fuel.

8.1. Data Sources

MassDEP's *Baseline Emission Inventory* supplied the data on the emissions of area source diesel engines. The U.S. Census supplied data on the number of roofing contractors in Massachusetts.

8.2. Number of Area Source Diesel Engines

Roofing contractors use diesel-fueled kettles to heat the asphalt for residential and commercial roofs. The Census Bureau's County Business Patterns identified 379 establishments that worked in the roofing industry in Massachusetts in 2002, based on the NAICS code 23816. These contractors represented all roofers that work in the roofing industry, including those contractors working with materials other than asphalt. Thus, this number is an overestimate, although asphalt is the dominant roofing material in the U.S.[130] For the purposes of this inventory, MassDEP estimated that each roofing entity used at least one asphalt roofing-kettle; however, larger roofing sites may require more than one asphalt roofing-kettle to conduct their work.

8.3. PM Emissions of Area Source Diesel Engines

In 2002, hot applied asphalt roofing-kettle engines emitted 10 tons of diesel $PM_{2.5}$ and no coarse PM. Thus, the $PM_{2.5}$ fraction represented 100% of PM_{10}. According to the *Baseline Emission Inventory*, MassDEP estimated the emissions by using EPA's emission factor for PM_{10}[131] and applying the factor to

[129]MassDEP, *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia*, June 2006.
[130]U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, *Asphalt Fume Exposures During the Application of Hot Asphalt to Roofs: Current Practices for Reducing Exposures* (DHHS Publication No. 2003-112, June 2003).
[131]U.S. EPA, Emissions Inventory Improvement Program (EIIP), *Area Sources Preferred and Alternative Methods*. (STAPPA, ALAPCO, EPA OAQPS Planning and Standards MD-14, Volume III, EPA-454/R-97-004c, July 1997).

$PM_{2.5}$. The Asphalt Institute of Kentucky estimated that 173,136 tons of roofing asphalt was used in Massachusetts in 2002. Emissions were then apportioned to counties based on NAICS Code 235610, as provided by the Census Bureau's reports on County Business Patterns. MassDEP assumed an emission factor of 4.5 lb. per PM_{10}/ton of asphalt melted based on EPA's AP-42.[132, 133] For additional information on the emissions estimation method, see the *Baseline Emission Inventory*.

[132]MassDEP, 2006.
[133]U.S. EPA, Office of Air Planning and Standards, Office of Air and Radiation, *Compilation of Air Pollution Emission Factors: Volume I: Stationary Point and Area Sources* (AP-42, 5th Ed., January 1995).

8.4. References for Area Source Diesel Engines

California Air Resources Board, Stationary Source Division, Mobile Source Control Division. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles*. October 2000.

Massachusetts Department of Environmental Protection (MassDEP). *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia.* June 2006.

U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. *Asphalt Fume Exposures During the Application of Hot Asphalt to Roofs: Current Practices for Reducing Exposures*. DHHS Publication No. 2003-112. June 2003.

U.S. Environmental Protection Agency (EPA), Emissions Inventory Improvement Program (EIIP). *Area Sources Preferred and Alternative Methods*. STAPPA, ALAPCO, EPA OAQPS Planning and Standards MD-14, Volume III, EPA-454/R-97-004c. July 1997.

U.S. EPA, Office of Air Planning and Standards, Office of Air and Radiation. *Compilation of Air Pollution Emission Factors: Volume I: Stationary Point and Area Sources.* AP-42, 5th Ed. January 1995.

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9.0. Conclusions

Diesel-powered engines affect every part of our lives, shuttling the majority of our children, food, electronics, and myriads of other goods. Unfortunately, diesel engines emit diesel $PM_{2.5}$, which has been shown to increase asthma rates and is a probable carcinogen. Due to the health and environmental effects associated with diesel $PM_{2.5}$, MassDEP developed *The Massachusetts 2002 Diesel Particulate Matter Inventory*. This inventory identified the number of diesel engines and the amount of diesel $PM_{2.5}$ emissions in 2002 in order to be consistent with other state planning horizons. Sources of data for this effort included the U.S. Census Bureau, EPA, the Massachusetts DMF, the state's Vehicle Inspection Database, railroad companies, and MassDEP's Stationary Source Emission Inventory System.

In Massachusetts, there were approximately 121,700 registered on-road diesel vehicles and 481,000 out-of-state vehicles traveling on the state's roads in 2002. Another 71,000 engines were off-road, land-based engines that were comprised of construction and mining engines, industrial engines, commercial equipment engines, and six other engine groups. Marine engines, which are categorized by their purpose and displacement, comprised over 10,000 engines. Locomotives, with almost 260 diesel engines, stationary sources with over 1,000 engines, and area sources with just 359 engines, completed the remaining number of diesel engines in the state.

Of these sectors, the following engine groups comprised the greatest number of diesel engines in 2002:

- **On-road heavy-duty diesel vehicles weighing 26,001 lbs. or more** (48,600 engines)
- **On-road diesel engines weighing less than 10,000 lbs**. (35,500 engines)
- **Construction and mining engines** (29,200 engines)

MassDEP also calculated the diesel $PM_{2.5}$ emissions of the state's diesel engines, identifying diesel-fueled on-road engines (1,860 TPY) and land-based, off-road engines (1,726 TPY) as the primary contributors to diesel $PM_{2.5}$ ambient emissions in Massachusetts. Together, these two sectors emitted 89% of the diesel $PM_{2.5}$ in 2002. Marine engines emitted 247 TPY, or 6% of diesel $PM_{2.5,}$ and locomotive engines emitted 142 TPY, or 4% of diesel $PM_{2.5}$. Stationary diesel engines and area source engines emitted only 32 TPY and 10 TPY, respectively, or a little more than one percent of the entire inventory in 2002.

Of the diesel engine sources in the inventory, the following five engine groups emitted the most diesel $PM_{2.5}$ in 2002:

- **On-road heavy-duty diesel vehicles weighing 26,001 lbs. or more** (1,587 tons or 40% of all $PM_{2.5}$);
- **Construction and mining equipment engines** (1,113 tons or 28% of all $PM_{2.5}$);
- **Industrial equipment engines** (289 tons or 7% of all $PM_{2.5}$);
- **C1 and C2 commercial marine engines** (222 tons or 6% of all $PM_{2.5}$); and,
- **Commercial equipment engines** (198 tons or 5% of all $PM_{2.5}$).

Except for heavy-duty diesel vehicles weighing more than 26,000 lbs., the $PM_{2.5}$ emissions for the several classes of on-road diesel engines were low, despite their high engine numbers. The 35,500 diesel vehicles weighing 10,000 pounds and under emitted just 3% of diesel $PM_{2.5}$ and the 13,400 vehicles weighing 19,501 to 26,000 pounds emitted only 3%. The 24,000 engines weighing 10,001 to 19,500 pounds emitted just 1% of diesel $PM_{2.5}$.

MassDEP also estimated the average diesel $PM_{2.5}$ emissions of individual engines. On a per engine basis,

- **Individual diesel locomotives emitted the most diesel $PM_{2.5}$.** Although line-haul and switchyard locomotive engines collectively emitted only 4% of total $PM_{2.5}$, per engine locomotive emissions were 0.5 TPY.

- **C1 and C2 commercial marine engines emitted more diesel $PM_{2.5}$ per engine than other groups (0.07 TPY**). Off-road construction and mining engines, industrial equipment engines, on-road vehicles weighing over 26,000 lbs., and stationary diesel engines were also significant per engine diesel $PM_{2.5}$ emitters (0.03 TPY each).

On the other end of the spectrum, data indicate that small and C1 recreational marine engines, on-road vehicles weighing 10,000 lbs. and under, and on-road vehicles weighing 19,501 to 26,000 lbs. emitted less $PM_{2.5}$ on an average per engine basis (0.003 TPY, 0.003 TPY, and 0.008 TPY, respectively) than other groups.

MassDEP identified several data gaps in this inventory. More current data needs to be obtained on the number of out-of-state on-road diesel engines traveling on the state's roads. Likewise, data on educational marine engines, government marine engines, stationary diesel engines, stationary diesel engines and asphalt roofing sources, need to be more accurate and specific. In addition, data on the type of fuel used must be further refined in the future. Currently, data on marine engines and stationary diesel engines group diesel oil and diesel fuel together under the umbrella category of distillate fuel.

With the recent federal mandate for ULSD fuel in every sector except area sources, and new $PM_{2.5}$ standards for on-road and off-road diesel engines promulgated by EPA, total $PM_{2.5}$ emissions from diesel trucks, buses and off-road equipment will be reduced by 90 percent.[134] Marine and locomotive engines will also be significantly cleaner as a result of recently promulgated national emission standards. In the meantime, all forms of existing diesel engines, from marine recreational vessels to off-road construction and mining equipment, will continue to emit diesel $PM_{2.5}$ at less restrictive emission levels and, in some cases, with no emission limits at all (pre-1996 model year construction engines, for example). This represents a significant challenge in protecting the health of workers and the general public. The information contained in this inventory may therefore be useful in identifying those engines that can be targeted for emissions reductions in order to protect the public's health and the environment.

[134] U. S. EPA, "New Clean Diesel Rule Major Step in a Decade of Progress," May 11, 2004. Available on-line at: http://yosemite.epa.gov/opa/admpress.nsf/b1ab9f485b098972852562e7004dc686/f20d2478833ea3bd85256e91004d8f90?OpenDocument.

9.1. References for Conclusions

U. S. Environmental Protection Agency (EPA). "New Clean Diesel Rule Major Step in a Decade of Progress." 11 May 2004. Available on-line at: http://yosemite.epa.gov/opa/admpress.nsf/b1ab9f485b098972852562e7004dc686/f20d2478833ea3bd85256e91004d8f90?OpenDocument.

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10.0 Figures

Figure 2-1.
Percent of Diesel-Powered Engines in Massachusetts in 2002
Including Out-of-State On-Road Engines (Total = 686,445 Engines)

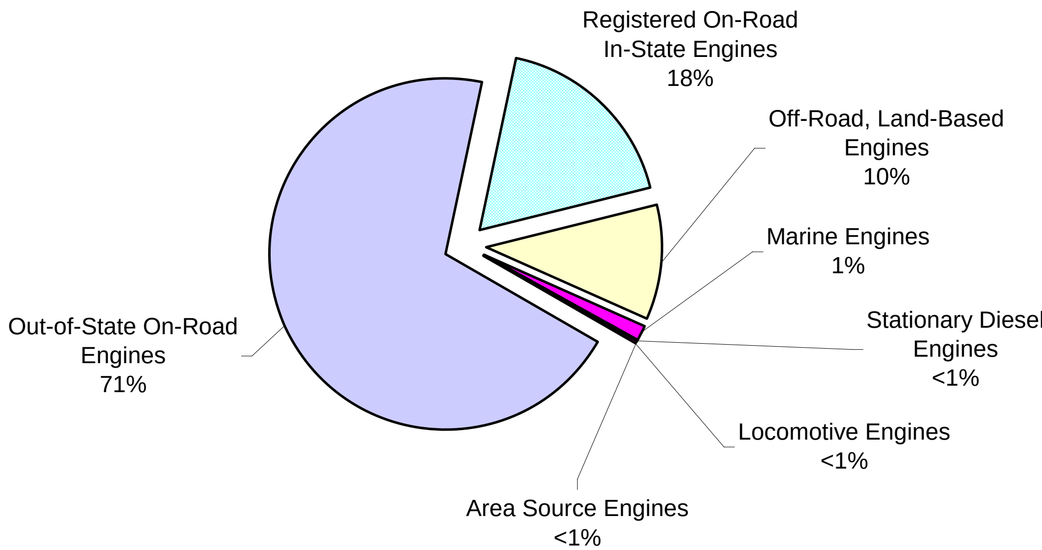


Figure 2-2.
Diesel-Powered Engines in Massachusetts in 2002, By Percent
Excluding Out-of-State On-Road Engines (Total = 205,445 Engines)

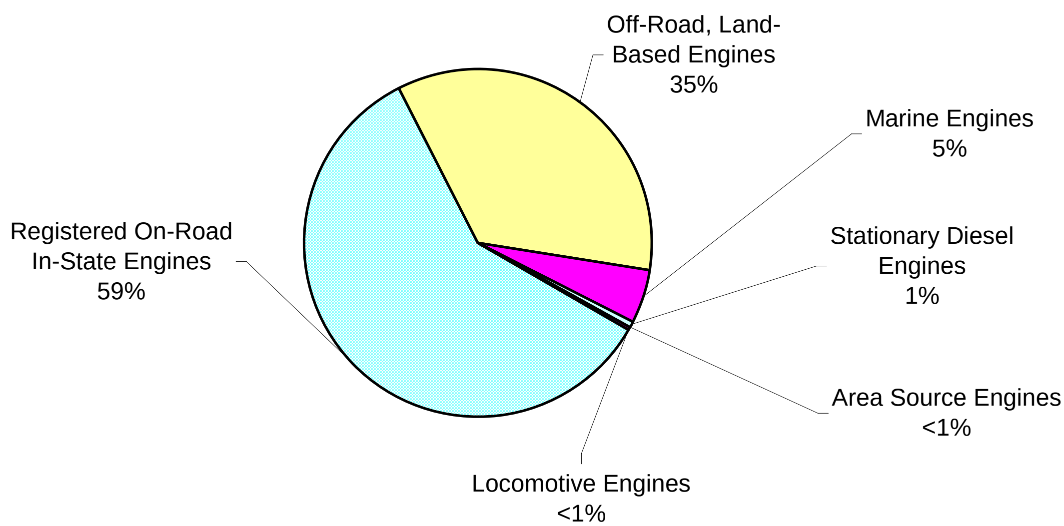


Figure 2-3.
Categories of Diesel Engines in Massachusetts in 2002, By Percent
(Including Out-of-State On-Road Engines)

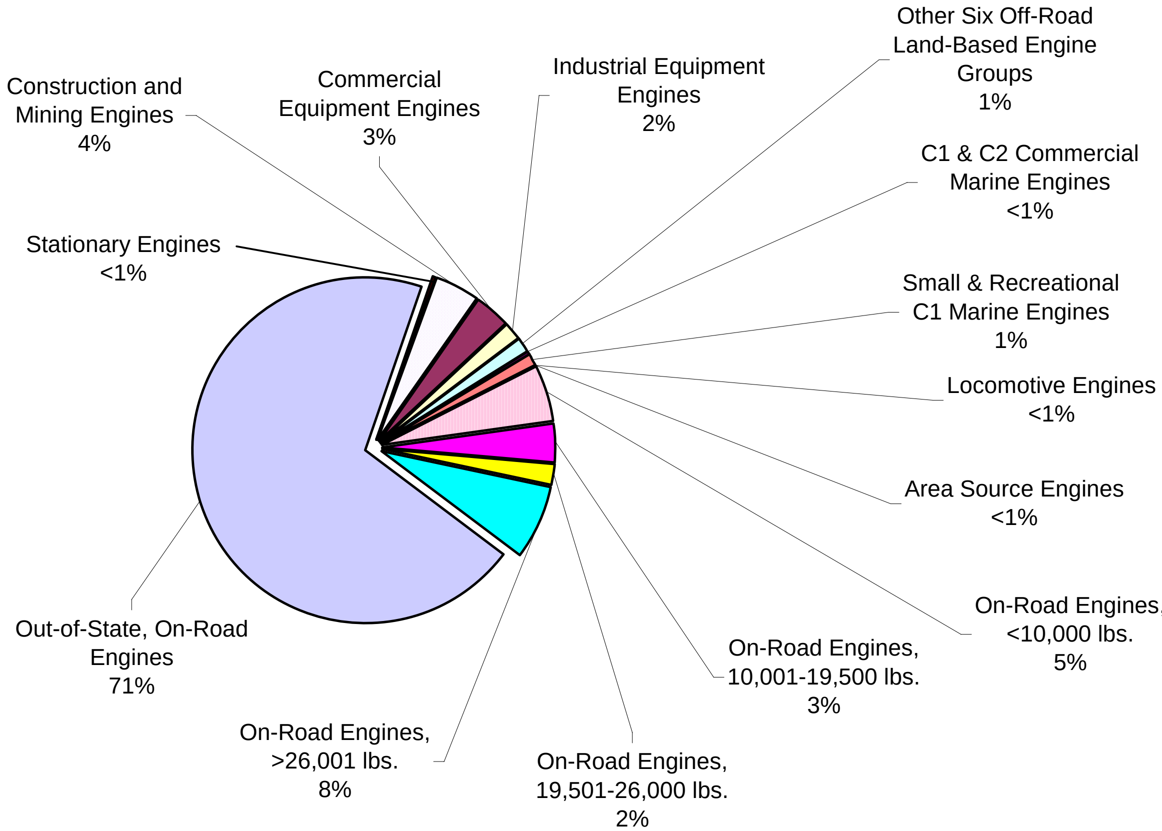


Figure 2-4.
Categories of Diesel Engines in Massachusetts, By Percent
(Excluding Out-of-State On-Road Engines)

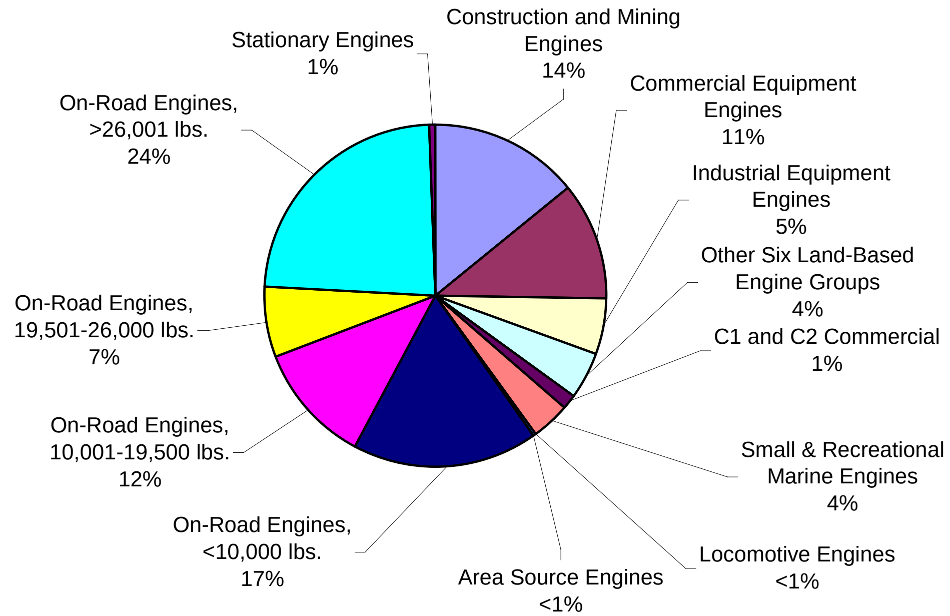


Figure 2-5.
Diesel PM2.5 Emissions, All Massachusetts Sources
(Percent of 4,017 TPY)

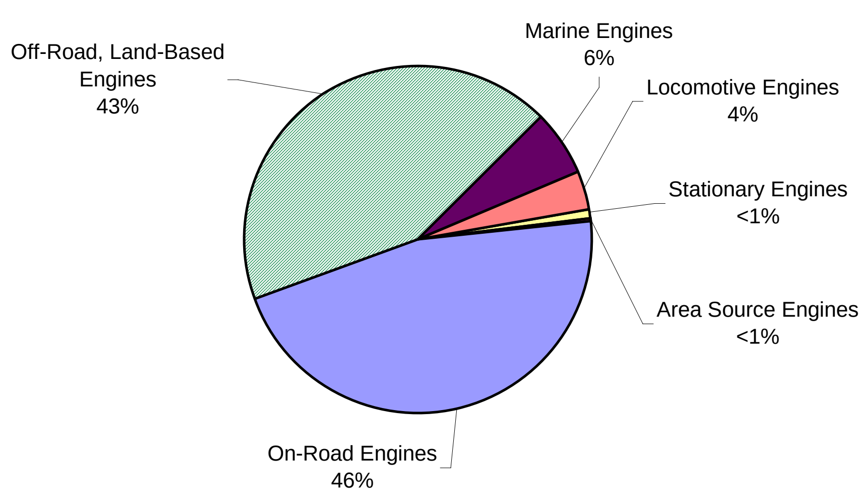


Figure 2-6.
Diesel PM2.5 Emissions, All Massachusetts Sources, Detail
(Percent of 4,017 TPY)

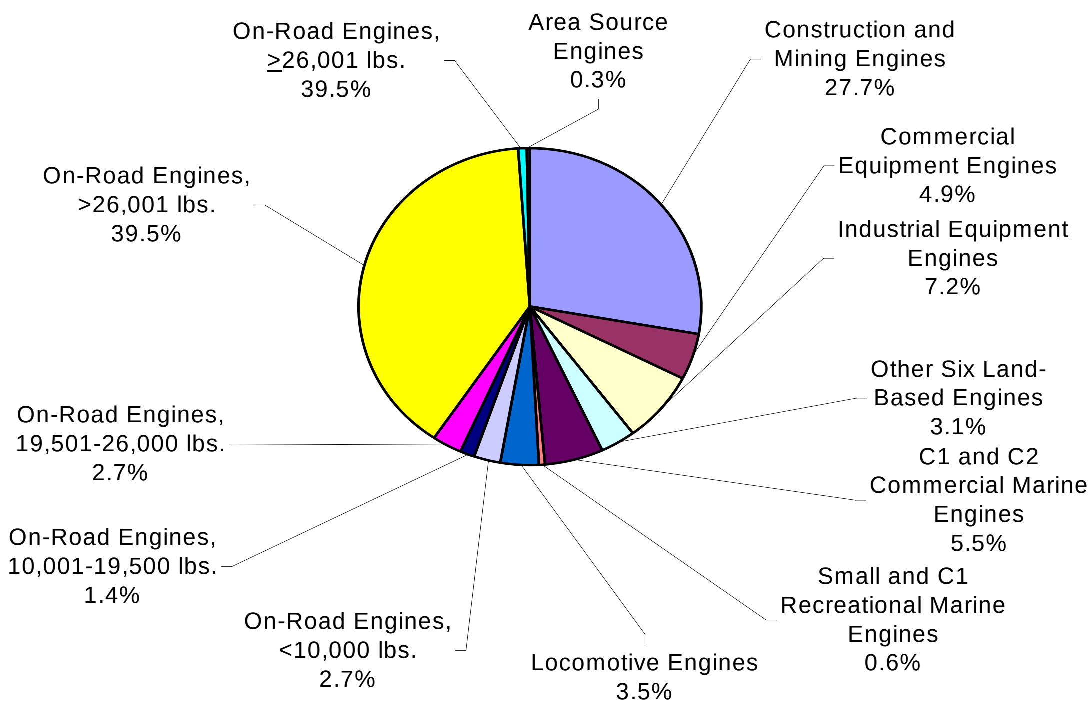


Figure 2-7.
Average Per Engine PM2.5 Emissions, By Engine Sector

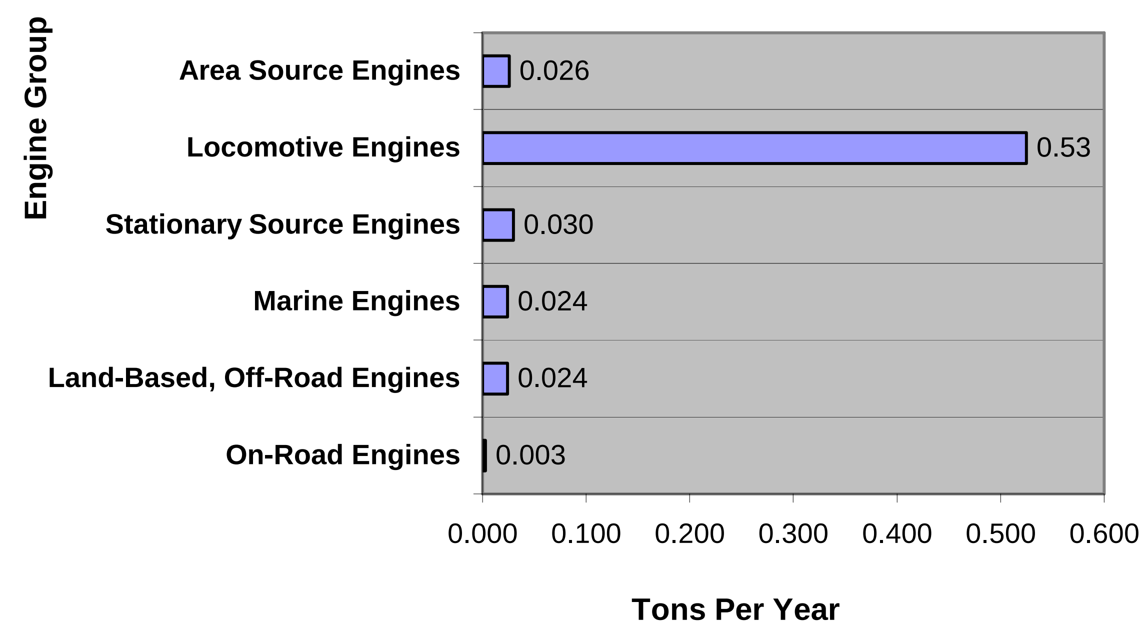


Figure 2-8.
Average PM2.5 Emissions, By Engine Groups in Each Sector

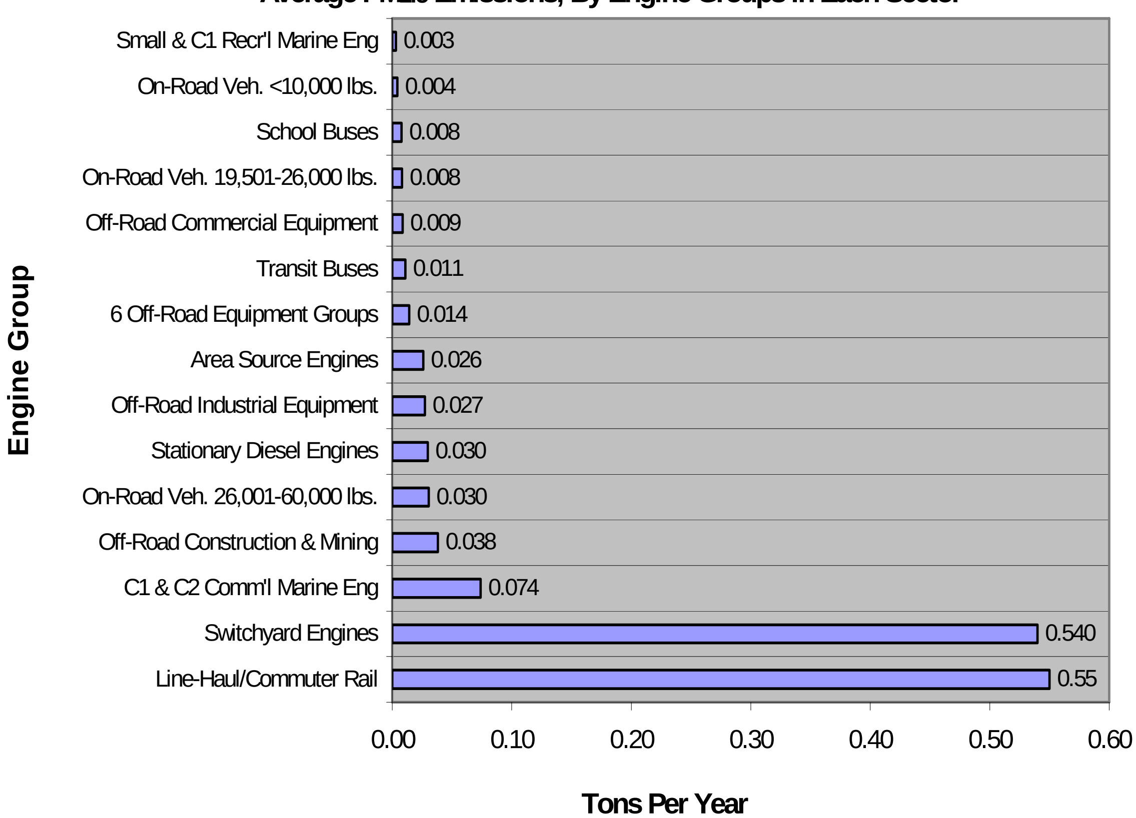
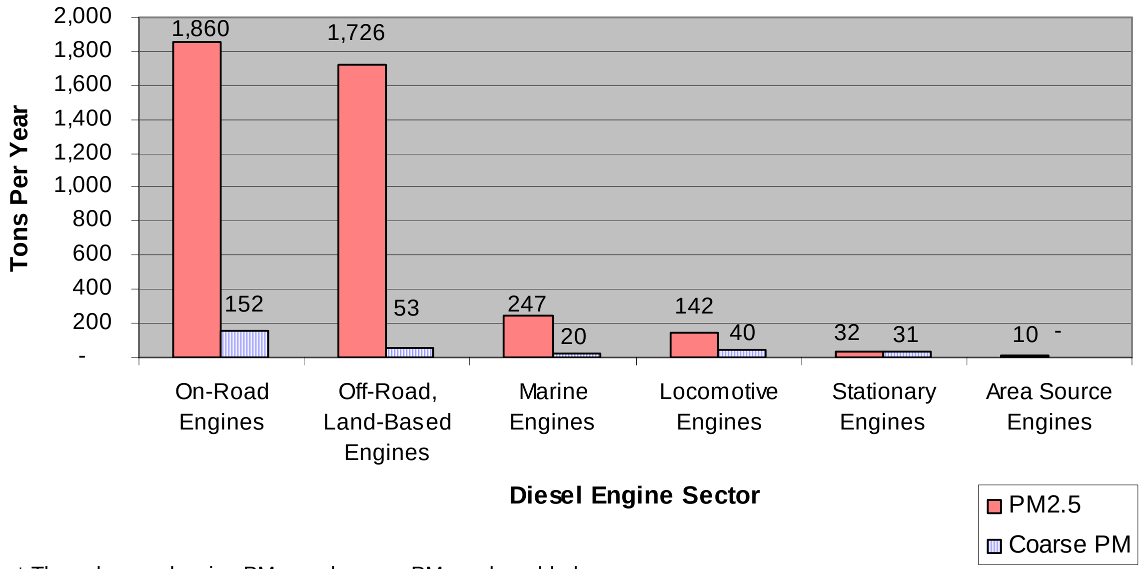
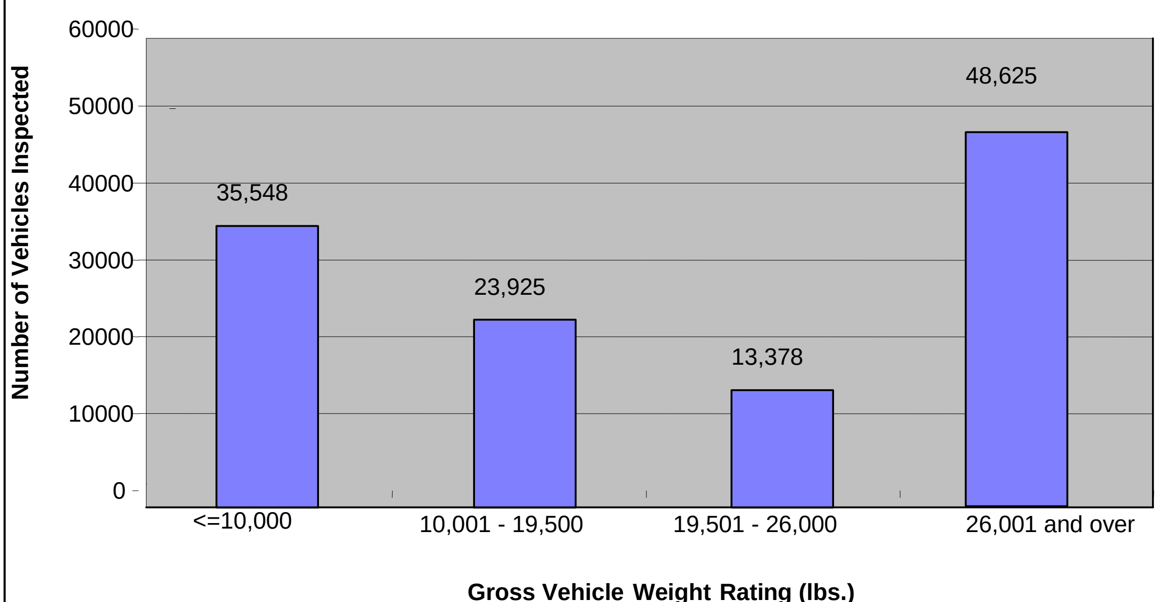


Figure 2-9.
Diesel PM2.5 and Coarse PM Emissions in 2002, All Sectors*



* The columns showing $PM_{2.5}$ and coarse PM can be added up to total PM 10.

Figure 3-1.
Massachusetts On-Road Diesel Vehicles, By Weight Class



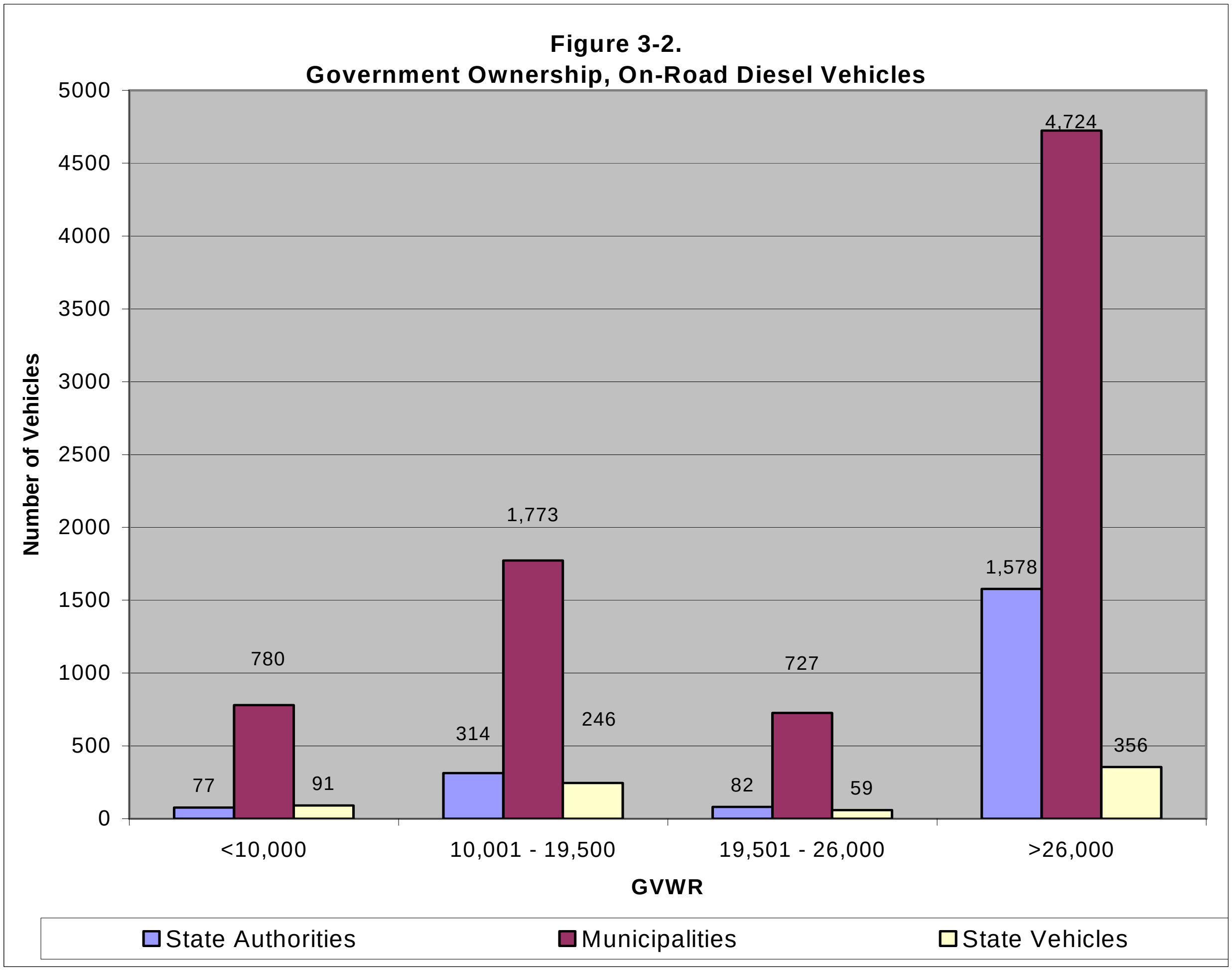


Figure 3-2.
Government Ownership, On-Road Diesel Vehicles
Number of Vehicles
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
77
780
91
314
1,773
246
82
727
59
1,578
4,724
356
<10,000
10,001 - 19,500
19,501 - 26,000
>26,000
GVWR
State Authorities
Municipalities
State Vehicles

Figure 3-3.
On-Road Diesel Vehicles, By Model Year

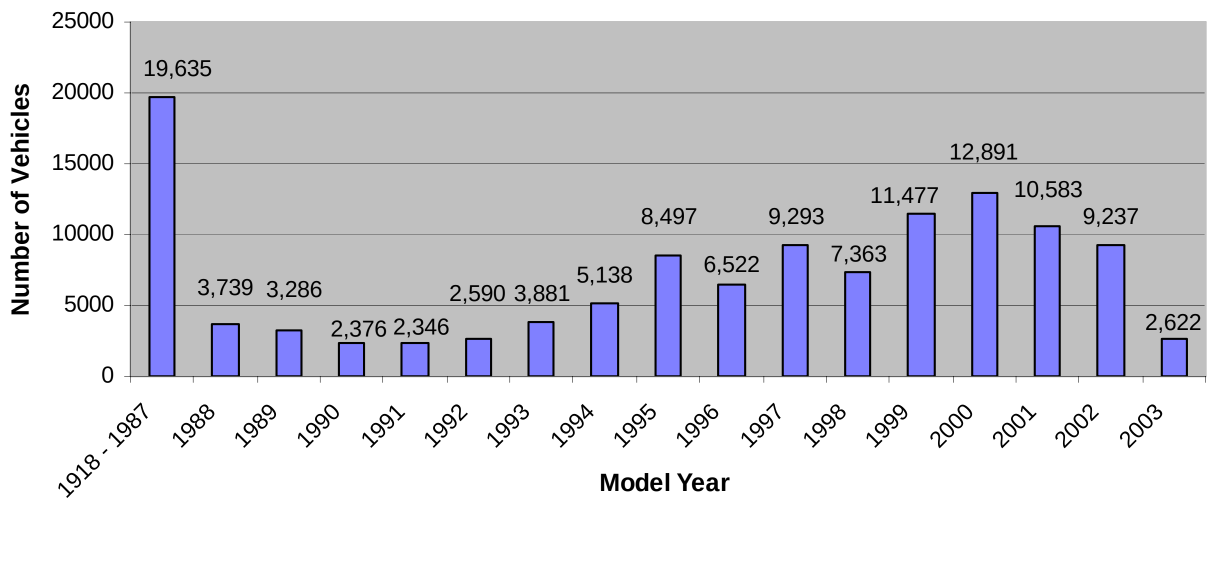


Figure 3-4.
On-Road Diesel Vehicles: <10,000 lbs. and under GVWR

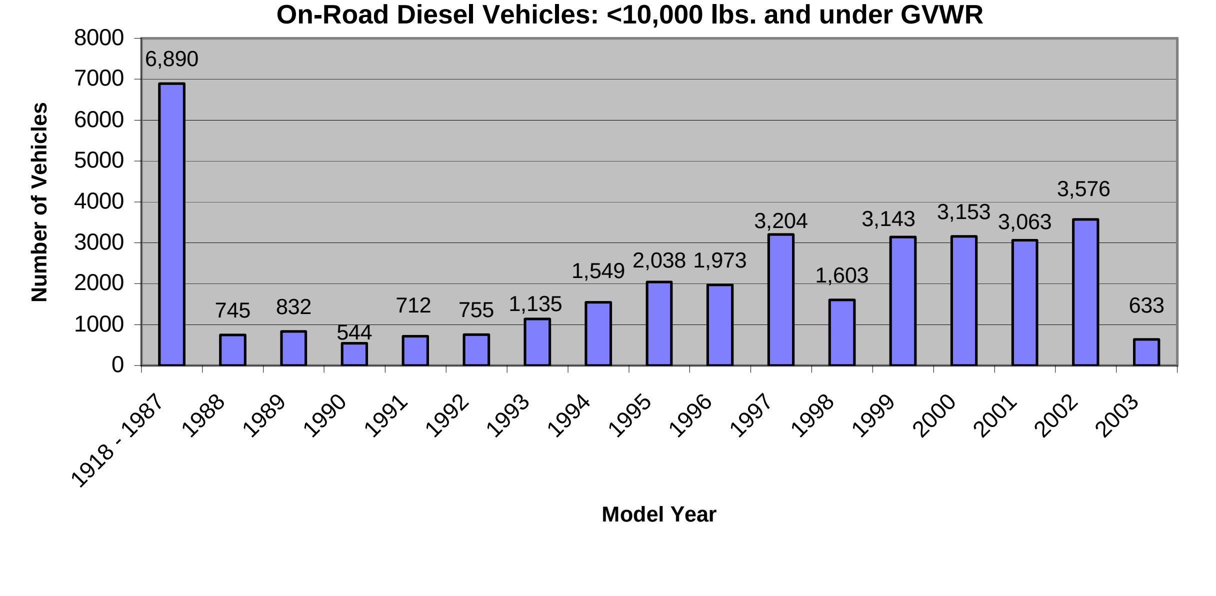


Figure 3-5.
On-Road Diesel Vehicles: 10,001 - 19,500 lbs. GVWR

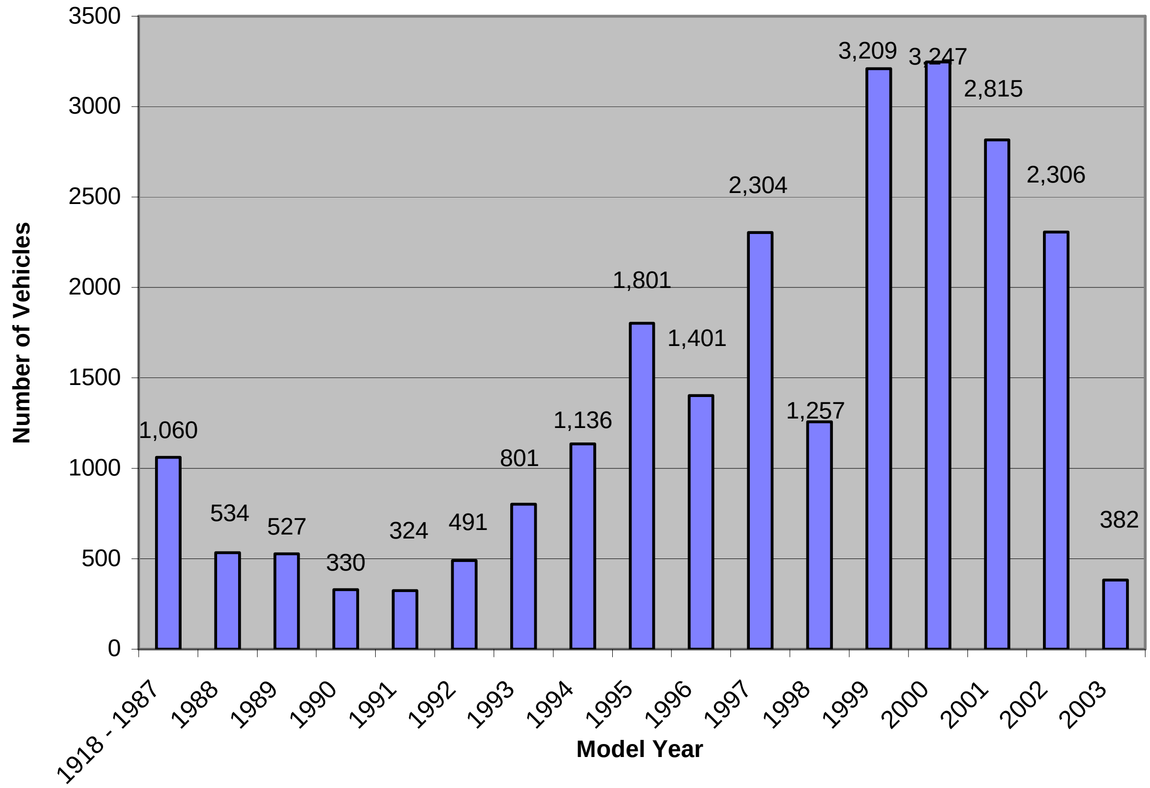


Figure 3-6.
On-Road Diesel Vehicles: 19,501 - 26,000 lbs. GVWR

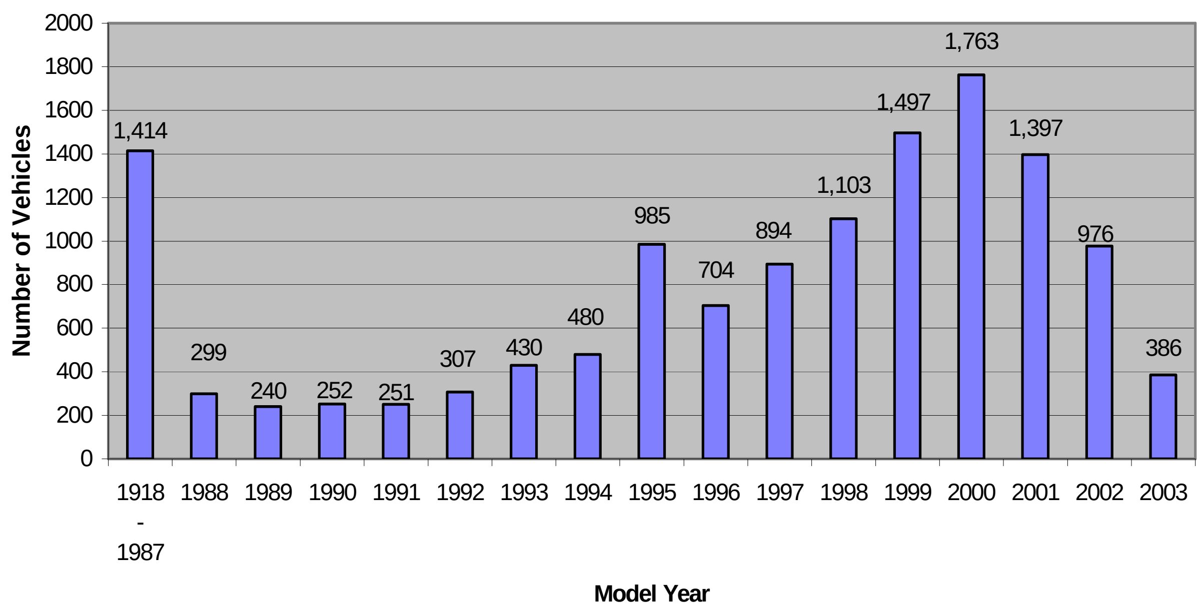


Figure 3-7.
On-Road Diesel Vehicles: 26,001 lbs. and Over GVWR

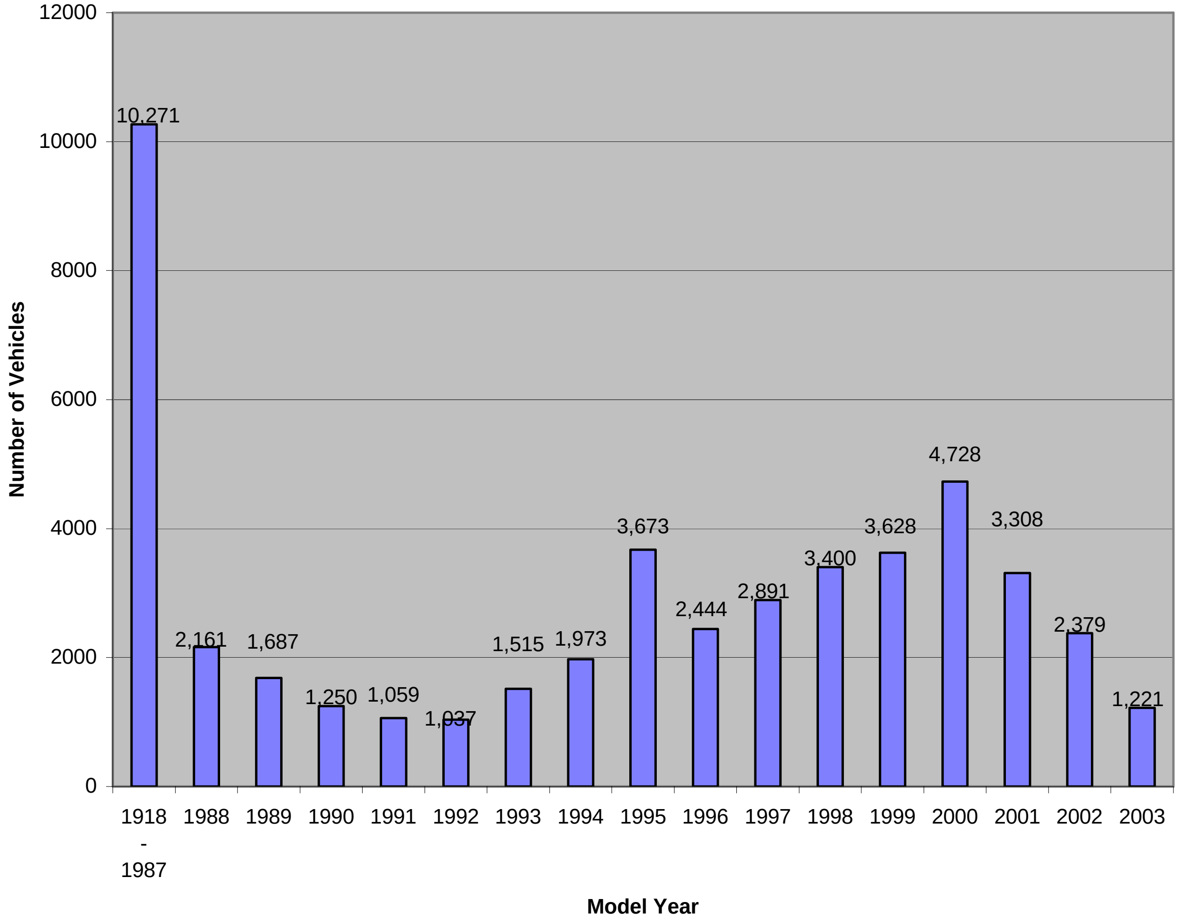


Figure 3-8.
2002 Exhaust PM2.5 Emissions, On-Road Diesel Vehicles

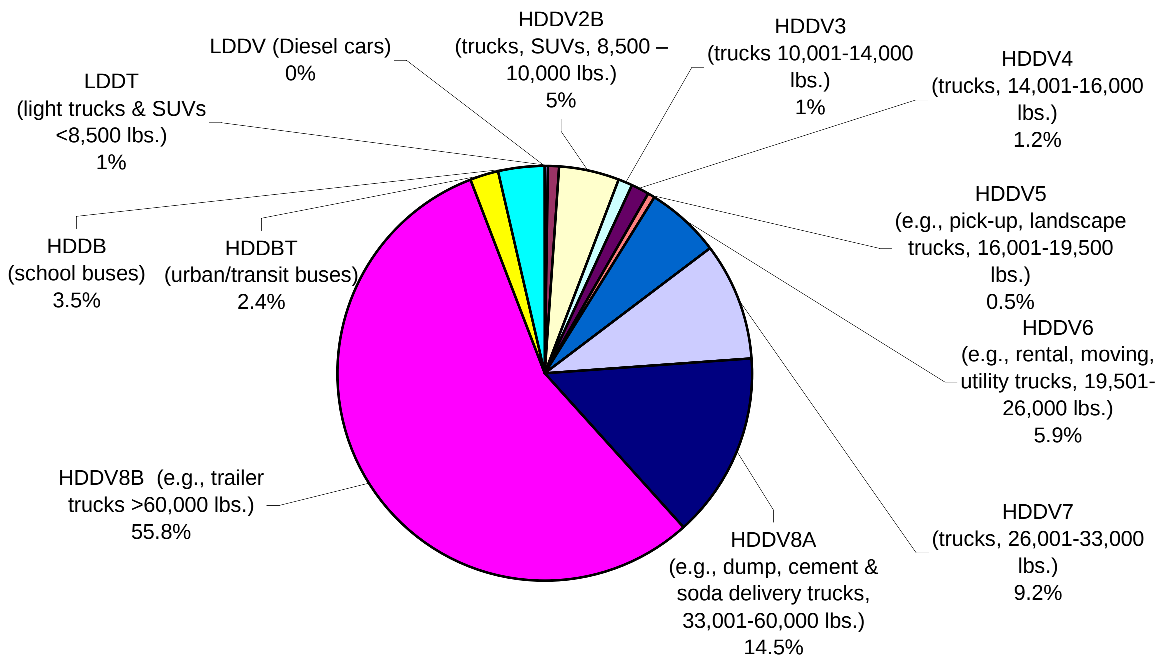


Figure 3-9.
Diesel PM2.5 and Coarse PM Emissions in 2002
On-Road Vehicles

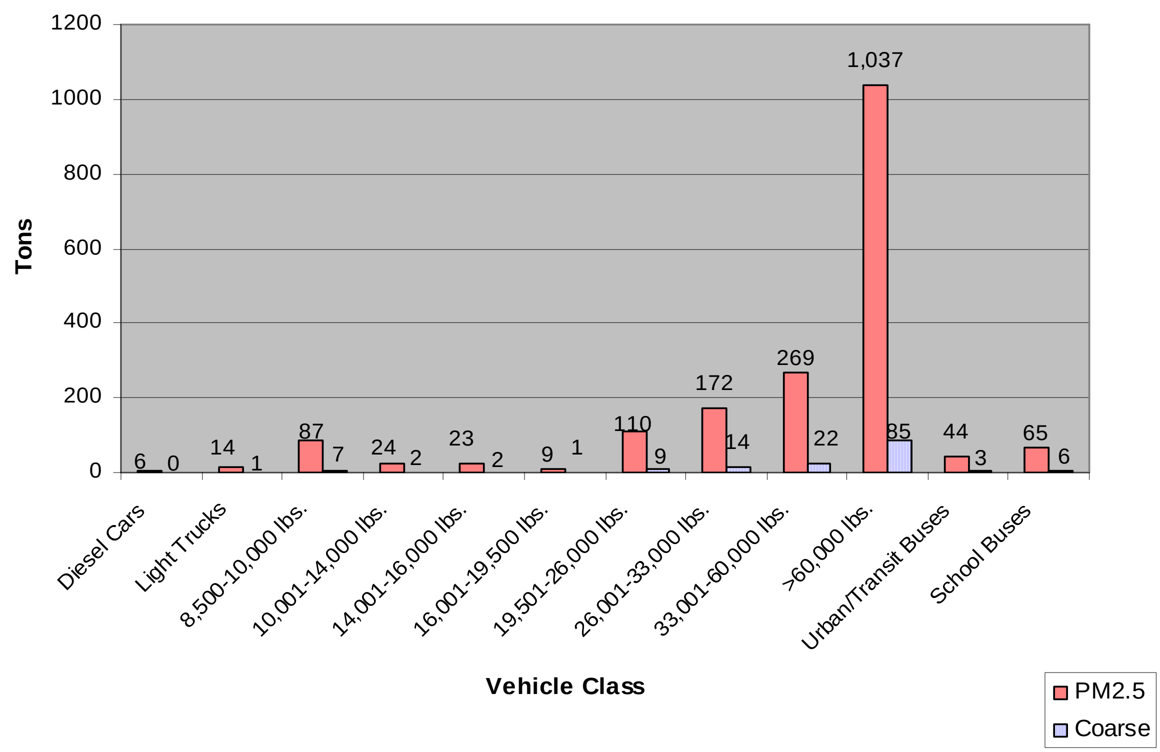


Figure 4-1.
Diesel Engine Groups in Off-Road, Land-Based Diesel Engine Sector

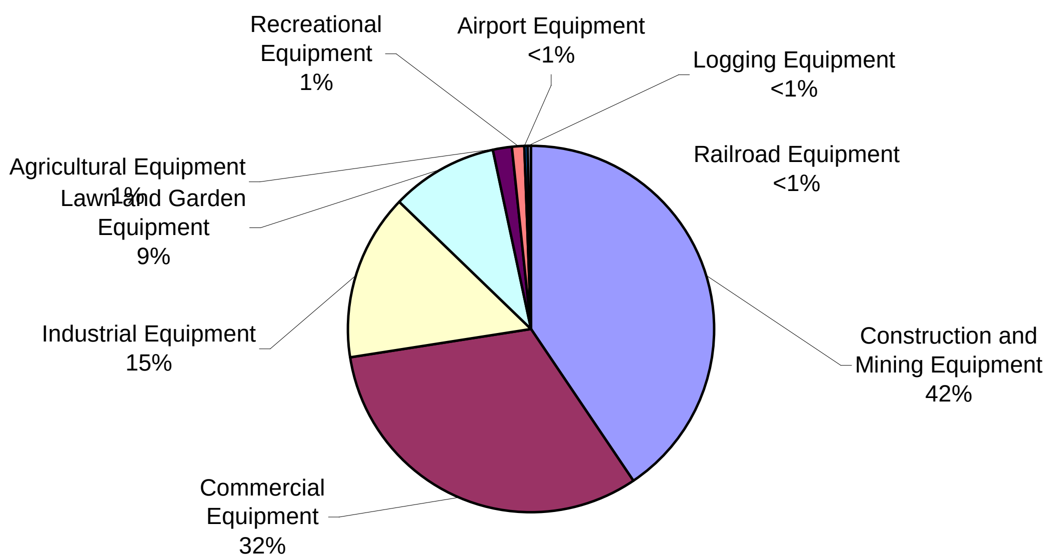


Figure 4-2.
Ownership of Off-Road Vehicles, By Plate Type (Percent of 2,700 Vehicles)

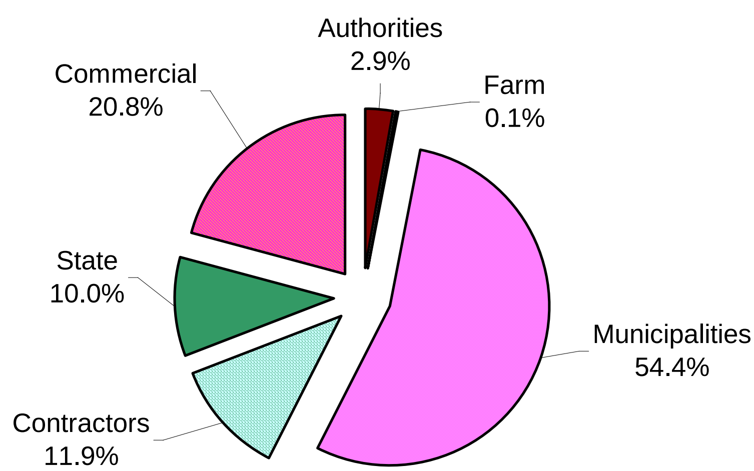


Figure 4-3.
Diesel PM2.5 Emissions, Off-Road, Land-Based Engines

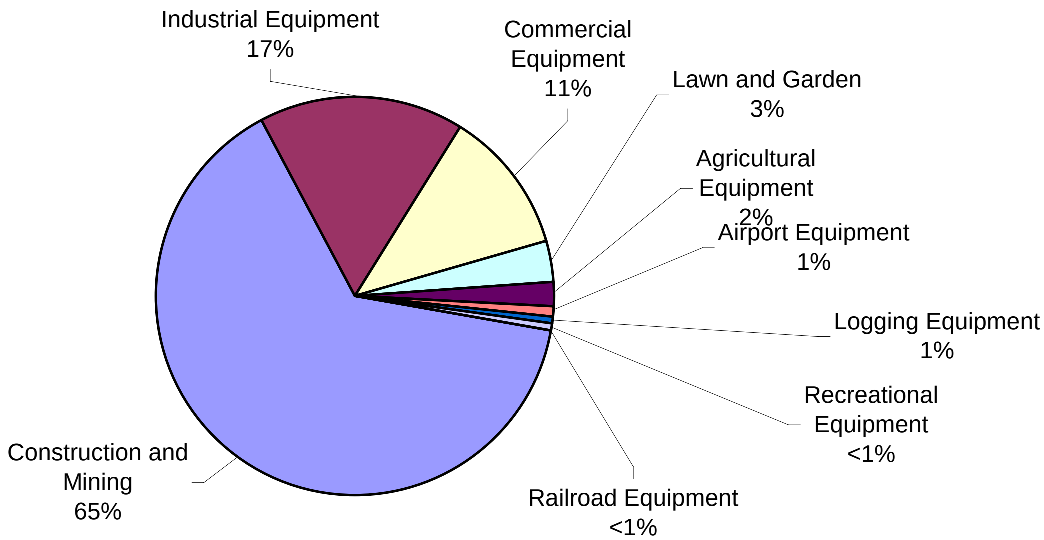


Figure 4-4.
Diesel PM2.5 and Coarse PM Emissions,
Off-Road, Land-Based Engines

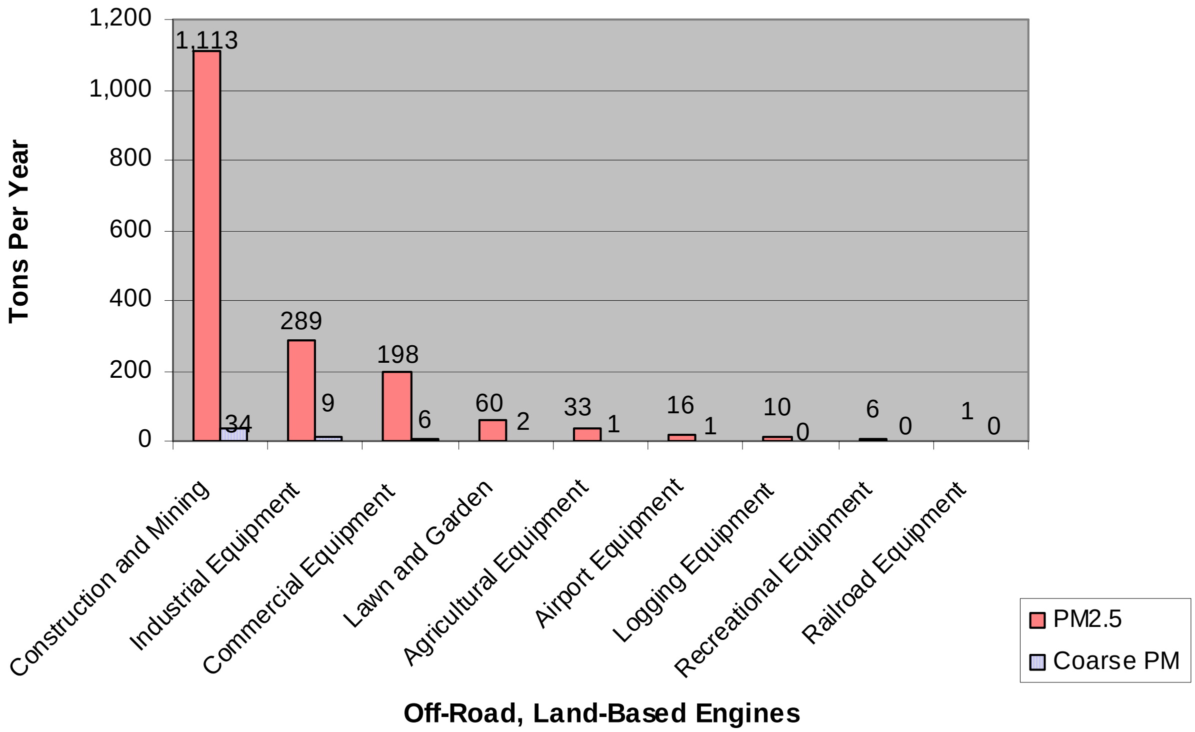


Figure 5-1.
Percent of Marine Diesel Engine Types in Massachusetts

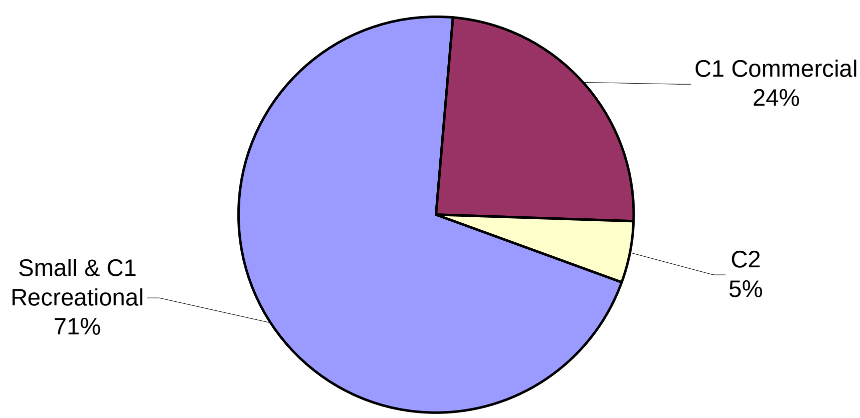


Figure 5-2.
Number of C1 Commercial Engines

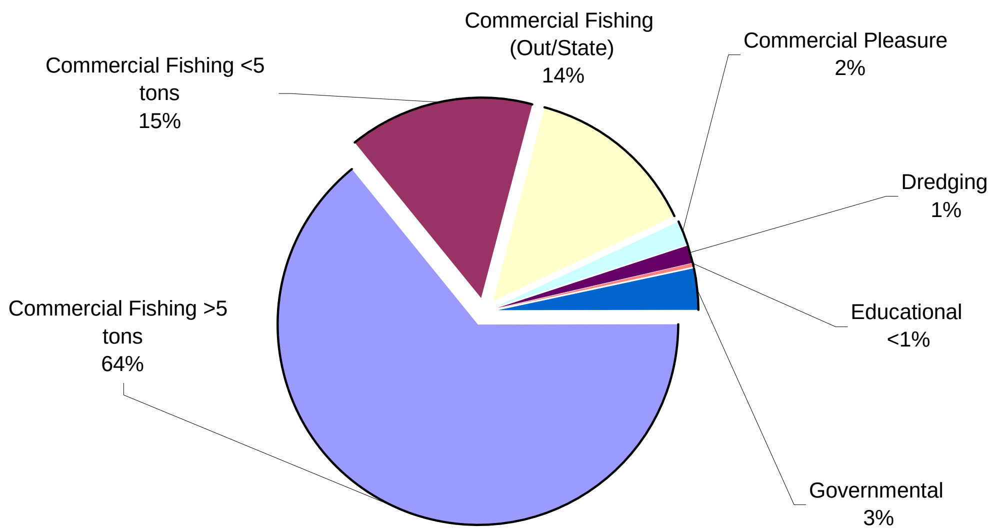


Figure 5-3.
C2 Marine Engines in Massachusetts (Total=526 Vessels)

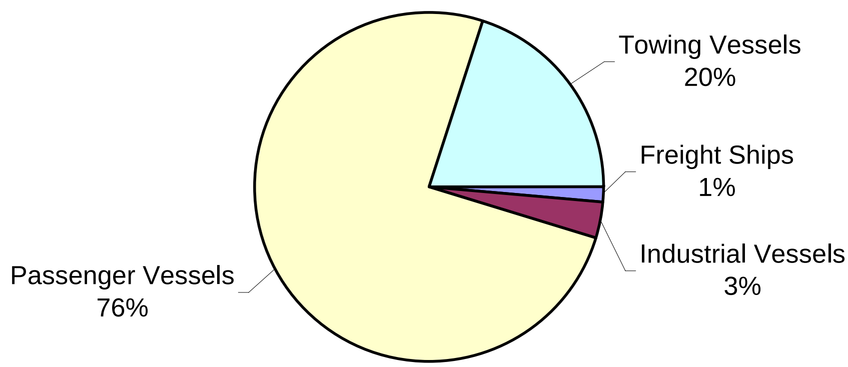
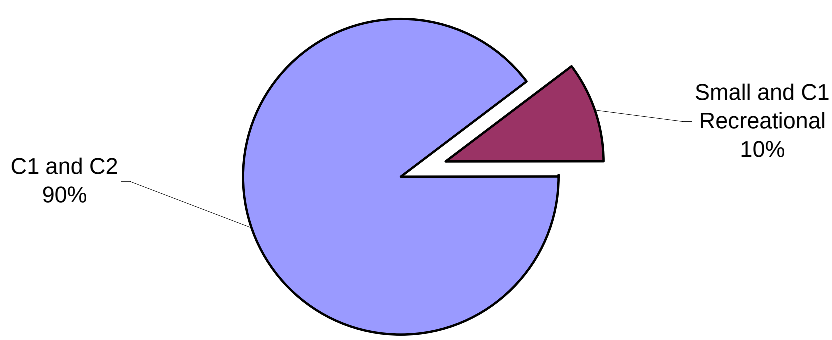


Figure 5-4.
$PM_{2.5}$ Emissions, Marine Vessels
(Total = 247 tpy)



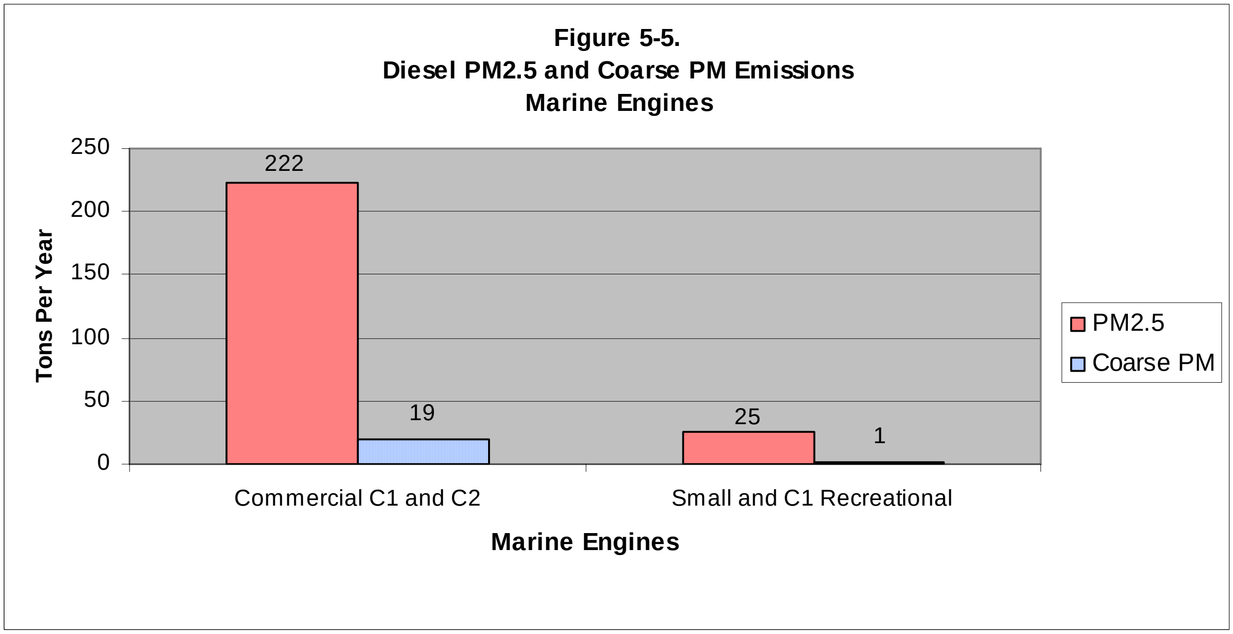


Figure 5-5.
Diesel PM2.5 and Coarse PM Emissions
Marine Engines
Tons Per Year
250
200
150
100
50
0
222
19
25
1
Commercial C1 and C2
Small and C1 Recreational
Marine Engines
PM2.5
Coarse PM

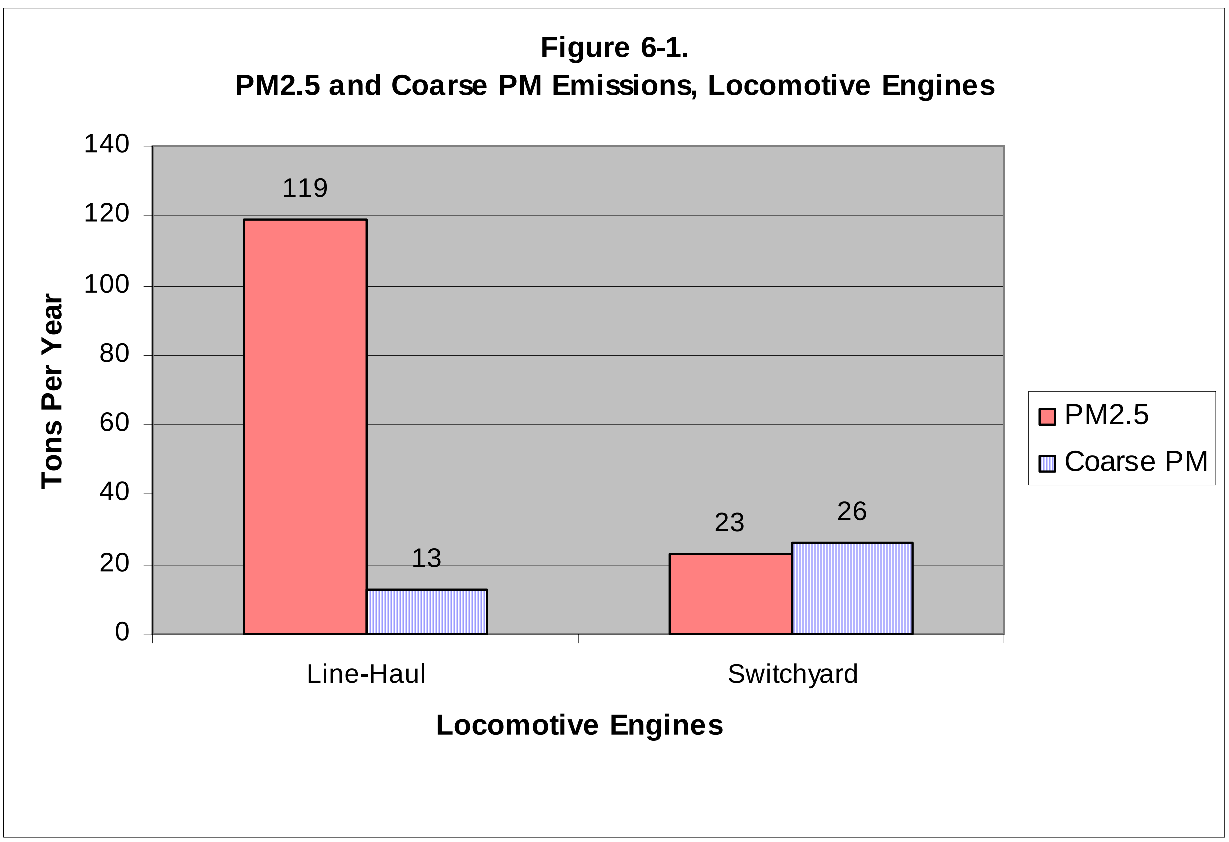


Figure 6-1.
PM2.5 and Coarse PM Emissions, Locomotive Engines
Tons Per Year
140
120
100
80
60
40
20
0
119
13
23
26
Line-Haul
Switchyard
Locomotive Engines
PM2.5
Coarse PM